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THE CONTRIBUTION OF AFTERBURNING TO THE AIRBLAST FROM ALUMINIZED EXPLOSIVES (U)

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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THE CONTRIBUTION OF AFTERBURNING TO THE AIRBLAST FROM ALUMINIZED EXPLOSIVES (U)

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ABSTRACT: Experiments were performed to evaluate the afterburning effect for aluminized chemical explosives. The results show that two afterburning processes can occur: the post-detonation reaction of aluminum with the detonation products and the reaction of the explosion products with air. Maximum blast performance in the 2- to 30-psi range in air and in nitrogen occurs for aluminum concentrations close to 20 per cent by weight.

The slightly oxygen-deficient explosive (TNETB) showed little air-afterburning; as aluminum was added to it, air-afterburning became more pronounced. The moderately oxygen-deficient explosive (RDX-wax) exhibited extensive air-afterburning which decreased as aluminum was added, but the air-afterburning effect was always greater than that for TNETB.

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THE CONTRIBUTION OF AFTERBURNING TO THE AIRBLAST
FROM ALUMINIZED EXPLOSIVES (U)

NAVORD Report 6234 reported an investigation of the afterburning contribution to the airblast from pure organic explosives. The work presented in this present report extends this line of investigation into the complex area of aluminized explosives. The study is submitted as a partial solution to the key problem in explosives research and development set forth in NAVORD Report 3906, entitled, "Develop Improved Explosives to Increase Lethality of Air Defense Weapons."

The experimental work that provides the basis for this study was performed under Task NOL RUUO-3-E-014/2121 WF 008-10-004 in 1960. The report was prepared under ORD-033-222/092-1/F009-08-05 PA 1. The data, their treatment, and the conclusions derived from the data have been used in-house on many occasions. The purpose of this report is to make this still valid and useful information available to all investigators interested in aluminized explosives.

The original rough draft of this report was prepared by C. C. Matle and E. M. Fisher, neither of whom are with the Laboratory any longer. The tedious task of reviewing and editing the copy was performed by T. O. Anderson.

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By direction

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

1. INTRODUCTION

The Naval Ordnance Laboratory has been conducting an investigation of the afterburning contribution to airblast from chemical high explosives. In the first phase of the program, Phase I, reported in NAVORD 6234 (Reference (1)), only pure organic explosives were studied. The work reported here was accomplished under Phase II, in which the earlier studies were extended to include aluminized explosives.

Afterburning, as used in this report, refers to the chemical reactions occurring in an explosion subsequent to detonation. Such post-detonation reactions are generally exothermic. In most instances, they result from the further oxidation of detonation products, wherein oxygen is extracted from the ambient air. (It is assumed that all of the oxygen contained in the explosive molecule is used up in oxidizing the initial detonation products, but since many explosives are oxygen deficient, additional oxygen is required to carry this process to completion.) In the case of explosives containing non-detonable additives, however, other afterburning reactions can be of significance -- in particular, those reactions between the additive and the detonation products themselves. In the present study, interest has been confined primarily to that part of the afterburning process occurring soon enough after detonation to contribute energy to the shock (blast) wave produced by the explosion.

The earlier work of Phase I on pure organic explosives provided an acceptable, though tentative basis for understanding the afterburning phenomenon. With this understanding to build on, the present phase, dealing with the complex and militarily important aluminized explosives, was initiated.

The use of aluminum as a high-energy additive to high explosives dates back to World War II. It is well known that the addition of this metal to an organic explosive improves shock wave performance within pressure ranges of military importance, both in air and under water. This occurs in spite of the fact that the addition of aluminum generally decreases the detonation rate (low detonation rates are usually characteristic of poor explosives) and aggravates the oxygen deficiency of explosives that are already oxygen-deficient. This improved performance has been generally attributed to the large heat of combustion of aluminum. It has been surmised that, should the available oxygen in an explosion be utilized by aluminum rather than by the organic fuel (hydrogen and carbon compounds), the net energy release would be increased, leading, in turn, to an improved shock wave performance.

It was hoped that the study of the afterburning effects of aluminized explosives in the present program would clarify the role of the aluminum in the explosion process. Such clarification would lead not only to a better understanding of the thermochemistry involved, but would also provide a more reliable and systematic basis for the development of optimum-performance mixtures of aluminized explosives for various applications. It is believed that these aims were satisfied in part; more work, however, remains to be done.

In addition to the experiments performed with aluminized explosives, it was found advantageous to use the same experimental field set-up to conduct several afterburning tests on the explosive Pentolite (non-aluminized). These tests, in effect, rounded out the Phase I experience.

2. EXPERIMENT

2.1 General Method

Explosives with varying oxygen deficiencies and with varying aluminum contents were fired in two gaseous media, air and pure nitrogen. Those fired in nitrogen were contained in neoprene balloons. The air-blast performances of these explosives were determined on the basis of peak pressure and impulse measurements, and the results for the series of tests in air were compared with those obtained in nitrogen. The tests in nitrogen were assumed to be completely free of afterburning effects, i.e., the nitrogen did not react chemically with the detonation or explosion products. By this means, the effects of afterburning could be directly ascertained as a function of the oxygen deficiency of the explosive matrix and as a function of the aluminum content.

2.2 Test Explosives

The test explosives used were TNETB and RDX/wax with various percentages of aluminum, and non-aluminized Pentolite (PETN/TNT, 50/50). Properties of these explosives and their components are given in Table 1. Non-aluminized TNETB, fired in air, was chosen as the control tests to link Phase I and Phase II experimental techniques, charges, and instrumentation performance. The results of TNETB shots fired in Phase II were compared with the results from similar shots in Phase I to ascertain constancy in instrumentation and charge performance.

The pure organic explosive TNETB is only slightly oxygen deficient, requiring an additional 0.04 grams of oxygen per gram of TNETB for complete combustion of the hydrogen to H_2O and the carbon to CO_2. The non-aluminized RDX-wax is moderately oxygen deficient, requiring 0.28 gram of oxygen per gram of explosive for complete combustion. The negative of each of these numbers (i.e., -0.04 and -0.28) is usually given as the value of the oxygen balance (O.B.) to CO_2 of the explosive in question. The oxygen balance is defined as the mass of oxygen contained in unit mass of explosive in excess of the amount needed for the full combustion of the explosive material. By this definition the oxygen balance for an oxygen-deficient explosive will have a negative value. Thus, the present study is concerned with the afterburning of two series of aluminized explosives, one with slightly oxygen-deficient matrices and one with moderately oxygen-deficient matrices.

The third organic explosive studied, Pentolite, also serves to extend the Phase I work. It was originally chosen not only because it is

a widely used material, but also because it is a mixture of an oxygen-rich and an oxygen-poor explosive. It was hoped that its performance might indicate the independent or interdependent behavior of the two explosive components in detonation.

2.3 Techniques of Measurement and Data Reduction

2.3.1 Explosion Effects

Peak shock overpressure and positive impulse were the shock wave parameters used in evaluating the airblast performances of the test explosives. The peak pressure (P_s), defined as the maximum overpressure in the shock wave, was determined by the velocity method (References (1) and (2)). The shock front velocity and the ambient speed of sound were measured by recording arrival times at nine face-on tourmaline piezoelectric gage stations in the 2 to 30 psi pressure region (see Figure (1)). The speed of sound was determined by the two-cap method, which also provided information for a wind-speed correction to the shock front velocity. Peak pressures were calculated with the aid of a computer program, using the Rankine-Hugoniot equation that relates shock velocity to peak overpressure.

Total positive impulse, I, is defined by the time integral $\int_0^T Pdt$, where P is the shock wave overpressure at time t, and T is the duration of the positive phase of the blast wave. Included in I is the contribution to the impulse made by that portion of the secondary shock for which the pressure is in excess of atmospheric pressure. Calculations were also made of the positive impulse (II) that excludes the contribution of the secondary shock in the positive phase.

The positive impulse data were obtained by mechanically integrating the pressure-time records produced by eight tourmaline gages (see Figure (2)). The pressure scale for the records was established using the peak pressures obtained by the velocity method. Corrections to the recorded peak pressures on the records were made to account for the effect of finite gage size. For details of the pressure-time recording equipment, see References (3) and (4).

Figures of merit were computed for the airblast performances of the explosives, as based on the peak pressure data, as follows: The mean values of the peak pressures observed at various scaled distances λ* were fitted to a curve by the least-squares technique. Then, using methods described in References (5) and (6), machine computations were made to determine the average weight of the

* The scaled distance, λ, is the distance from the charge, in feet, divided by the cube root of the charge weight, in pounds.

explosive used as a standard for basis of comparison - TNETB in N_2 in the present instance - that would produce the same peak pressure at the same distance as that produced by the test explosive. This figure of merit is termed the equivalent weight on a pressure basis (EW_P).

A corresponding figure of merit was obtained using graphic plots of the scaled impulse data (positive impulse divided by the cube root of the charge weight) vs scaled distance, following the techniques described in Reference (5). This figure is termed equivalent weight on an impulse basis (EW_I).

Another figure of merit was determined from the impulse data excluding the contribution of the secondary shock. This figure of merit is designated EW_{IX}.

2.3.2 Balloon Techniques

The charges fired in nitrogen-filled balloons were suspended as shown in Figure 3. To position each charge precisely in the center of the balloon, two cords of equal length were affixed to the charge harness. The charge harness consisted of a sling made up of four equally spaced marlin lines. The spacing of the marlin lines was held fixed by two to three equatorial wraps of friction tape. The charge was then placed within the balloon and the two cords fastened to the balloon, one at the neck, the other at a hole formed at a point diametrically opposite the neck. The two holes were sealed and the balloon inflated. Suspension lines attached to the balloon were then used to position the system relative to the gages. This method provided a precise and unvarying centering of the charge within the balloon. Since the balloons were translucent, the charges could be aligned and positioned accurately with respect to the gages with the aid of a transit.

The balloons were J-100 and J-300 neoprene balloons, weighing 100 grams and 300 grams, respectively, manufactured by the Dewey and Almy Chemical Company. Since the internal pressure obtained in the inflated balloons was only 1 millibar over ambient air pressure, ambient atmospheric pressures were assumed in the program. Figure 4 illustrates the field arrangement for a typical balloon shot.

2.3.3 Light Intensities

Cathode ray oscillographic (CRO) records of the light intensity vs. time were obtained for a number of the shots. A Type 925 photo-tube, sensitive primarily in the region of 8,000 Å, was

used for detection. CRO sweep durations on the order of 100 milliseconds were employed to record photo-tube outputs. This made it possible to detect light emission in the visible and infra-red regions from the relatively slow post-detonation processes. (Only 0.25 millisecond is required for the shock wave to reach the balloon surface, a distance of 2.2 feet from the charge.) The photo-tube system had a response time in the order of 0.1 millisecond.

2.4 Properties of Gases

Nitrogen gas was used in the balloons for those shots designed to exclude reaction of the detonation products with the surrounding air (air afterburning*). This gas was chosen rather than an inert gas or carbon dioxide, because its thermodynamic properties are more nearly like those of air; also the densities and specific heat ratios of the inert gases and carbon dioxide differ appreciably from those of air.

The nitrogen was obtained from compressed-gas bottles. The purity of the gas was 99.9 per cent. Calculations showed that the maximum amount of oxygen available for afterburning in the nitrogen shots (consisting of any oxygen impurity in the gas plus the oxygen in any entrapped air in the balloon) was about one gram, or less than 0.7 per cent of the amount of oxygen contained in each test explosive.** The effects of these impurities were thus ignored in the study.

2.5 Charges

The charges were bare, 3.25-inch diameter spheres with nominal weights of 1 pound. All the test charges were centrally initiated with Engineer Special detonators without the aid of boosters.

Data on the charges are given in the following table:

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* Evidence to date indicates that nitrogen is a product of detonation of pure organic explosives, and that atmospheric nitrogen takes no part in afterburning.

** The RDX-wax/Al (80/20) charges contained the least amount of oxygen of all the test charges, the amount being 150 grams.

	Parts by Weight	Loading	Weight (gm)	Variation in Charge Weight Max. Range (%)	Density	% T.M.D.[a]
TNETB	100	Cast	453	1.1	1.63	92
TNETB/Al	90/10	Cast	475	3.2	1.67	91
TNETB/Al	72/28	Cast	525	4.7	1.85	94
RDX-wax[b]	98/2	Pressed	416	0.8	1.47	83
RDX-wax/Al	90/10	Pressed	439	0.3	1.58	86
RDX-wax/Al	80/20	Pressed	443	0.7	1.59	84
Pentolite	100	Cast	483	0.0	1.65	96

(a) Percentage of theoretical maximum density (T.M.D.). Density of Al is 2.70

(b) Data from Phase I program (Ref. (1)).

2.6 Balloon Effects

In Reference (1), the results of an investigation into "balloon effects" were reported as part of the Phase I program. A study of the effect of balloon size was made to determine the distance (balloon radius) beyond which afterburning contribution to the air shock wave ceases. Experiments were performed with TNT in nitrogen-filled balloons of varying diameter. TNT was chosen because, being a highly oxygen-deficient explosive, it was expected to show after-burning contributions to the air shock at greater ranges than for the less highly oxygen-deficient explosives. Examination of the airblast data from these experiments revealed that a balloon radius of 2.25 ft. (4.5-ft. diameter) was sufficiently large to exclude the possibility of after-burning beyond the balloon enclosure.

The effect of the mere presence of the balloon on the air-blast was also studied. Spherical 1-pound Pentolite charges were exploded in 4.5-ft. diameter air-filled balloons and the airblast produced was compared with the airblast produced by similar charges exploded in free air. It was concluded from a careful examination of the data that the effect of the presence of the air-filled balloon was sufficiently small that it could be neglected.

2.7 Results

The charges fired in Phase II were composed of TNETB (0, 10, and 28 per cent aluminum), RDX-wax (10 and 20 per cent aluminum), and Pentolite (0 per cent aluminum). The nitrogen series was fired in 4.5-foot diameter balloons and the air series in free air. The peak pressure and positive impulse data obtained are tabulated in Tables 2, 3, and 4. Mean values of these parameters, plotted as a function of scaled distance on log-log graphs, are included in Figures 5 to 10. From these data, equivalent weights were determined, taking the performance of TNETB in nitrogen as a standard reference.

To justify the combined use of the equivalent weight results from both the present Phase II and the preceding Phase I studies, it was necessary to establish the reproducibility of the experimental techniques used. This was accomplished by firing a control explosive, TNETB in air, in both phases and comparing the results. This comparison is shown in Figure 11. Based on these results, the average performance figures of merit obtained in Phase II relative to those in Phase I were found to be:

$$(EW_P)_{II} = 1.06\ (EW_P)_I$$

$$(EW_I)_{II} = 0.98\ (EW_I)_I$$

$$(EW_{IX})_{II} = 0.98\ (EW_{IX})_I$$

It is generally accepted that for the techniques employed in these tests, deviations of 5 per cent, or less, in equivalent weight values are not significant. Inasmuch as two of the above equivalent weight evaluations are well within the insignificant zone and the remaining one, EW_P, is but 1 per cent above the significant zone, it was assumed that the differences in experimental techniques in the two phases were not significant. Consequently, the equivalent weights for the control in the present phase were adjusted to agree with those in Phase I. All the other equivalent weights obtained in the present phase were likewise adjusted. With these adjustments, direct comparisons could be made for all of the explosives tested in both Phases I and II.

The adjusted equivalent weight results are presented in Table 5-A. For easy reference, the equivalent weight results from the Phase I program are given in Table 5-B.

3. ANALYSIS AND DISCUSSION

3.1 EW Results

From the data presented in Table 5, evaluations of the equivalent weights for pressure and impulse criteria can be made in relation to:

Effect of aluminum

Effect of ambient gas

Effect of oxygen balance

Heat of detonation

This has been done in Tables 6-A through D.

Table 6-A shows the relative changes in blast performance due to the incorporation of aluminum in each explosive. It should be noted that the results for the 72/28 TNETB/Al are suspect. Subsequent investigations with TNETB/Al as an underwater explosive (Reference (7)) suggest that the charge is not adequately initiated without boostering. Since in this series of airblast experiments a single detonator alone was used, it is highly probable that improper initiation occurred for this highly aluminized explosive leading to lower values of blast parameters than would be expected from a properly initiated charge. Even with this reservation, in general aluminum significantly improves the performance of both TNETB and RDX in both air and nitrogen.

More specifically, the data indicate that aluminum is effective in increasing the blast performance for an oxygen-deficient explosive (RDX-wax) even where air-afterburning cannot occur. Thus, it can be expected that aluminized explosives, even if oxygen deficient, will have satisfactory blast characteristics when fired in an oxygen-deficient atmosphere, such as at high altitude.

Table 6-B shows the effect that the availability of oxygen in the ambient air for afterburning has on blast effectiveness. In all instances, improvements over identical charges fired in nitrogen are noted. Of interest is the result that, for RDX-wax/Al, the relative improvements in air decrease with increasing aluminum content, whereas the converse to some extent is true for TNETB/Al. The study by Gordon (8), using Tetryl (O.B. = -0.48) and Tetryl/Al (79/21) yielded a result similar to the present RDX-wax/Al result: he found the effect of ambient oxygen on blast performance was appreciably smaller for the aluminized explosive than for the pure organic explosive. Another result of interest seen in Table 6-B is the close agreement existing between the values of EW_P and EW_{IX} (within 6 per cent). The significance of this agreement is not apparent.

The experimental data presented in Table 6-C reveal no simple or direct correlation between oxygen balance and equivalent weight. If any relationship does exist, it is overshadowed by the effect of aluminum content.

In correlating the experimental equivalent weight data with heats of detonation (h_D), of various explosives, one must be satisfied with the use of calculated values of h_D; experimental values are few. For pure explosives (Phase I) an arbitrary water decomposition mechanism was used.* For aluminized explosives a modified form of this decomposition mechanism was tried; the oxygen was assigned first to the formation of aluminum oxide, then to the usual sequence of water vapor, carbon monoxide, and carbon dioxide. The resultant heat of reaction at 25°C and one atmosphere is computed from the heats of formation of the explosive and its detonation products. (Tables 1-A and 1-C list the pertinent heat-of-formation values.)

The h_D results for the test explosives, using this mechanism, are presented in Table 6-D, along with equivalent weight results from Table 5-A. Of particular interest are the ratios of EW_P/h_D and EW_{IX}/h_D given in the table. For the nonaluminized, or pure organic explosives, these ratios are seen to be nominally equal, having values ranging from 0.70 to 0.75.** In contrast, the ratios for the aluminized explosives are seen to be quite varied in value and, in all cases, lower than the values obtained for the nonaluminized explosives. This indicates that a modified water decomposition mechanism probably is not valid for aluminized explosives. This is not surprising. It has been shown (Reference (9)) that there is practically no hope of using a single arbitrary equation to fit the calorimetric heat-of-detonation data for different series of aluminized explosives - or even for the complete concentration range of a single series. In other words, a more sophisticated approach is required. The Ruby code (Reference (10)) is a possibility, but Ruby calculations have not been made for the compositions employed in this study.

Another point of interest to be inferred from the data in Table 6-D lies in the ratios obtained for Pentolite, 0.72 and 0.75. These are

* The arbitrary water decomposition mechanism, used in computing heats of detonation of pure organic explosives, assigns the oxygen in the explosive to the fuel components in a specific, decreasing order of preference: $H_2O(g)$, CO, CO_2. Heat of detonation is obtained by subtracting the heat of formation of the explosive from the sum of the heats of formation of these detonation products. Finally, the result is adjusted to a constant-volume condition. For details, see Reference (12).

** This equality, in fact, was used in Reference (1) as the basis for an analytical method of computing blast performances of explosives in nitrogen from calculated values of h_D. The particular expression used was $EW = Ch_D$, where C is a constant.

very close to the values obtained for the pure organic, "single" explosives tested in Phase I. This result lends support to the contention that the two explosives comprising Pentolite, PETN and TNT, react independently in detonation, for if one were to assume that Pentolite reacted as a single, combined, explosive, a calculated heat of detonation of only 1.01, instead of 1.20 kcal/gm would be obtained. This smaller h_D value would yield ratios of 0.86 and 0.90, values which are substantially higher than those obtained for other pure organic explosives. Here the Ruby code provides a possible answer but raises another problem. Ruby code calculations (Reference (11)) show that the h_D for Pentolite is the same whether one treats the Pentolite as a chemical compound or treats it as a mixture of independently-reacting materials. However, the h_D so calculated is 1.39 kcal/gm, a value too high to fit the h_D-EW relation developed in Phase I of this study. Obviously a reappraisal of Phase I and Phase II results using the Ruby code is in order.

3.2 Reaction of Aluminum

The EW results in Table 6-A show that with the addition of aluminum, appreciable improvements in the performances of both of the explosives tested occur in both air and nitrogen atmospheres. Since the aluminum replaces its weight of organic explosive, it must react exothermally in the explosion process: also, part, if not all, of this reaction must occur within a short time after detonation in order to enhance the shock wave performance, particularly in peak overpressure. It would seem reasonable to assume that the aluminum reaction does not involve ambient nitrogen to more than a negligible extent since, from Gordon's experiments (8), blast performance was shown to be less for explosions in nitrogen than in the inert gas, argon.* It also appears safe to assume that only a small or negligible amount of aluminum reacts during detonation of the organic explosive. This is supported by the fact that detonation velocities are reduced when aluminum is added to pure organic explosives, Reference (13). It is concluded, then, that the aluminum reaction is primarily a post-detonation, or "afterburning," reaction with the detonation products. A number of other results support this conclusion:

a) As has been observed in previous studies (1), (12), sustained, or post-detonation, reactions generally produce a forward shift of the secondary shock in the pressure-time curve. That is to say, the time interval between the arrivals of the primary and secondary shocks is decreased when post-detonation reactions occur. In the case of pure organic explosives, a nominally fixed position of the secondary shock relative to the primary, or initial, shock, can be ascribed to shots in nitrogen. Shots in air produce shifts forward, the shift increasing with increased afterburning. These relations are shown pictorially in Figure 12. In this figure, note especially the forward shifts in the

* The explosives tested, Tetryl and Tetryl/Al (79/21), are similar in thermochemical properties to those in the present program.

records for three of the aluminized explosives fired in nitrogen. (The absence of a shift for RDX-wax/Al (90/10) appears anomalous.) These shifts strongly indicate post-detonation exothermic reactions which, on the basis of the previous comments, can be ascribed to the reaction of aluminum with the detonation products.

b) Closely related to (a), above, is the increase of EW_I over EW_{IX} (Table 5). In the case of pure organic explosives, no increases are noted for nitrogen shots; in air, however, large increases are noted in all instances except for the nearly oxygen-balanced TNETB. For the aluminized explosives fired in nitrogen, small but definite increases (RDX-wax/Al (90/10) again appears to be anomalous, although consistent with the pictured data of Figure 12.)

c) More support in favor of a post-detonation aluminum reaction is found in a comparison of EW_I with EW_P. For pure organic explosives, differences of up to 3 per cent between EW_I and EW_P are noted for non-afterburning explosions (all those in nitrogen, plus TNETB in air). In contrast, those shots in air involving afterburning yield differences on the order of 15 per cent. For the aluminized explosives in nitrogen, smaller, but significant, differences are noted between EW_I and EW_P (7-9 per cent) which, again, are indicative of an afterburning reaction of aluminum.

d) The light intensity records (Figure 13) clearly show afterburning processes. The two explosive/gas combinations exhibiting only one sharp light peak (Pentolite in nitrogen and TNETB in air) are just the two for which no afterburning would be expected. All of the remaining records show either light pulses of extended duration or secondary radiation peaks. (Again RDX-wax/Al (90/10) exhibits only a weak afterburning effect.) It should be kept in mind that any contribution to shock wave performance (EW) must occur within much less than a millisecond after detonation; such times are completely unresolved in the records of Figure 13. It appears reasonable, however, to expect a qualitative correlation between the long-duration intensities exhibited and the blast performances.

Based on the above analysis, then, it is concluded that aluminum reacts extensively with the detonation products; the reaction is primarily an afterburning process as herein defined. A small, but significant, portion of the reaction occurs in sufficient time to contribute to shock wave performance.

3.3 Heat of Detonation Versus Equivalent Weight

In Phase I, a constant proportionality was found to exist between EW_P for explosions in nitrogen and calculated heats of detonation. A similar result was obtained using EW_{IX} for explosions in nitrogen. These relations could be stated mathematically as follows:

$$EW_P = 0.71 \cdot h_D$$

$$EW_{IX} = 0.70 \cdot h_D$$

where h_D is in kcal/gm, and the equivalent weights are relative to the results for TNETB, fired in nitrogen. In the analysis in section 3.1, above, it was shown that these proportionalities no longer hold in the case of the aluminized explosives when the calculated heats of detonation are obtained by assuming the maximum possible oxidation of aluminum.

Phase I results are based on heats of detonation computed with an arbitrary water decomposition mechanism; Phase II results have been shown inconsistent with that mechanism taken in its simplest form (i.e., with complete oxidation of aluminum). Both sets of data should be examined jointly when better heat of detonation data becomes available. In particular, heats of detonation as calculated by the Ruby code (Reference (10)) should be investigated when more results for aluminized explosives become available.

3.4 Pentolite in Air

The performance of Pentolite in nitrogen and its relationship to the heat of detonation has already been discussed (paragraph 3.1). As for the Pentolite results in air, large increases are noted for all EW values (Table 6-B). The light intensity results shown in Figure 13 illustrate the enhancement in the afterburning.

It is of interest to apply to Pentolite the analytic method that was developed in Phase I for calculating equivalent weights in air with respect to TNETB fired in nitrogen (Appendix B of Reference (1)). The basic equations needed are:

$$EW_P = 0.71 \left[h_D + \Delta h_P\right]$$

$$EW_P = 0.70 \left[h_D + \Delta h_{IX}\right]$$

where h_D = computed heat of detonation (kcal/gm)

Δh = heat contribution from afterburning (kcal/gm)

The subscripts P and IX refer to pressure and impulse (excluding secondary shock), respectively.

The terms Δh are obtained by computing, first, the amount of ambient oxygen, ΔO, used in the afterburning process. As shown in Reference (1) for explosions in air:

$$\Delta O_P = 0.24 \ (-O.B.)$$

$$\Delta O_{IX} = 0.31 \ (-O.B.)$$

Here, as before, O.B. is the oxygen balance of the explosive (gms oxygen/gm explosive). The additional oxygen, ΔO, is then assumed to react with the detonation products in the same order of preference as employed in the arbitrary water decomposition mechanism. (H_2O, CO, CO_2 order of preference). The energy release resulting from this afterburning reaction is Δh.

Since Pentolite consists of two organic explosives (in equal proportion by weight) it is assumed that the two components react independently in afterburning. Thus, the computations are performed separately for each component explosive. The equivalent weight of Pentolite can then be obtained by taking the mean of the EW values obtained for the two component explosives.

The following table presents the necessary data:

<u>Afterburning of Pentolite in Air</u>

Explosive	h_D	O.B.	ΔO_P	Δh_P	ΔO_{IX}	Δh_{IX}
PETN	1.42	-0.10	0.024	0.10	0.031	0.13
TNT	0.98	-0.74	0.180	0.30	0.230	0.39

Using the values in the table, one obtains:

$$EW_{P(PETN)} = 0.71 \left[1.42 + 0.10 \right] = 1.079$$

$$EW_{P(TNT)} = 0.71 \left[0.98 + 0.30 \right] = 0.909$$

Thus, for Pentolite:

$$EW_P = 1/2 \left[1.079 + 0.909 \right] = 0.994$$

Similarly:

$$EW_{IX} = 1.02$$

These results are 5 per cent and 9 per cent below the experimental values of 1.05 and 1.12 given in Table 5-A. Considering the crude nature of the method used, one finds these differences not unreasonable.

4. RECOMMENDATION

The afterburning data from both phases of this study should be reexamined using Ruby code determinations of the heats of detonation when t[illegible] become available. The use of Ruby code data may permit develo[illegible]t of a general quantitative theory of afterburning applicable to both aluminized an[illegible] non-aluminized explosives.

5. CONCLUSIONS

Afterburning, in the case of aluminized explosives, involves two processes: the reaction of aluminum with the detonation products and the reaction of the explosion products with ambient oxygen. Both can produce appreciable increases in blast performance. The contribution of each process is apparently related to the oxygen balance of the organic component.

The contribution obtained from the reaction between aluminum and the detonation products (aluminum afterburning) is greater for moderately oxygen-deficient explosives (RDX-wax/Al) than for slightly oxygen-deficient ones (TNETB/Al). The contribution from reaction of the explosion products with ambient oxygen is also greater for the RDX-wax/Al than for the TNETB/Al, as measured by the increase in EW in going from a nitrogen to an air atmosphere. This difference in air-afterburning becomes less and less significant as the aluminum content is increased. The two contributions are not additive.

The present study was not intended to, and did not, determine the optimum aluminum content in a given explosive so far as air blast in an oxygen-free or reduced oxygen atmosphere is concerned; however, the results do indicate the optimum is in the neighborhood of 20 per cent, which is consistent with other studies. (See Reference (14), for example.)

Light intensity records show that extensive, long-duration explosion processes occur, due both to the afterburning of aluminum and of the explosion products.

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TABLE 1 - EXPLOSIVE THERMOCHEMICAL PROPERTIES

TABLE 1-A
PURE ORGANIC EXPLOSIVES

Explosive (1)	Chemical Formula	Molecular Weight	Oxygen Balance to CO_2	Heat of Formation (Kcal/mole)	Heat of Detonation (Kcal/gm) (2)	Heat of Combustion (kcal/gm) (2)
TNETB*	$C_6H_6N_6O_{14}$	386.2	-0.04	+118.6	1.446	1.620
RDX	$C_3H_6N_6O_6$	222.1	-0.22	-14.7	1.228	2.140
RDX-wax	98/2	--	-0.28	--	1.195 (3)	2.310 (4)
TNT	$C_7H_5N_3O_6$	227.1	-0.74	+17.8	0.984	3.490
PETN	$C_5H_8N_4O_{12}$	316.15	-0.10	+125	1.416	1.844
Pentolite* PETN/TNT	50/50 (by weight)	--	-0.42	--	1.200 (5) 1.007 (6)	2.667

* See footnotes on next page.

TABLE 1-C
EXPLOSIVE COMBUSTIBLE COMPONENTS

Component	Chemical Formula	Molecular Weight	Oxygen Balance	Heat of Formation (kcal/mol)	Heat of Combustion (kcal/mole)	Product of Combustion Assumed
Wax	CH_2 (chain)	14.03	-3.43	+5.5	146.55	H_2O, CO_2
Aluminum	Al	26.97	-0.89	--	380.00	Al_2O_3
Hydrogen	H_2	2.02	-8.0	--	57.80	H_2O (g)
Carbon	C	12.01	-2.67	--	94.05 26.42	CO_2 CO
Carbon Monoxide	CO	28.01	-0.57	+26.42	67.63	CO_2

TABLE 2

PEAK PRESSURE RESULTS

Notes common to all explosive mixtures in these tables:

1. Pressures are in psi.
2. $\bar{P}$ = Mean Overpressure.
3. λ = Scaled Distance $d/W^{1/3}$ $(ft/lb^{1/3})$.
4. $\% \sigma P$ = Standard Deviation in Per Cent.
5. $\% \sigma \bar{P}$ = Standard Error in Per Cent.
6. * Indicates data discarded in accordance with Chauvenet's Criterion.

TABLE 2

Peak Pressure - Pentolite in Free Air

Shot# \ λ	5.58	6.56	7.54	8.77	10.48	12.68	15.87	20.28
10WO-1	26.76	17.54	13.98	9.59	7.15	5.17	3.70	2.50
2	29.69	20.36	14.48	9.93	7.24	5.60	3.66	2.73
3	28.77	19.38	14.57	9.85	7.43	5.52	3.79	2.60
4	28.76	20.96	15.00	9.52	7.49	5.66	3.84	2.63
9	25.56	19.92	14.55	*10.80	7.78	5.63	3.79	2.69
12	25.23	23.80	14.55	10.27	7.57	5.11	3.81	2.37
57	26.05	17.42	13.95	9.57	6.93	4.97	*3.49	2.41
$\bar{P}$	27.26	19.91	14.44	9.79	7.37	5.38	3.77	2.56
$\%\sigma_P$	6.55	10.95	2.54	2.96	3.86	5.34	1.82	5.33
$\%\sigma_{\bar{P}}$	2.48	4.14	0.96	1.21	1.46	2.02	0.74	2.01

Peak Pressure - Pentolite in N_2

Shot# \ λ	5.58	6.56	7.54	8.77	10.48	12.68	15.87	20.28
10WO-58	23.94	16.15	12.36	8.51	6.67	4.40	3.26	2.25
59	24.44	16.04	13.13	8.91	6.61	4.91	3.46	2.45
60	24.73	17.12	12.09	8.65	6.64	4.77	3.39	2.32
62	24.79	16.42	12.51	7.86	6.68	5.25	3.51	*2.67
64	24.72	17.45	12.62	8.84	6.69	4.91	3.22	2.38
66	24.89	17.36	12.74	9.03	6.71	4.95	3.24	2.33
67	23.76	*14.26	11.54	8.14	*6.41	4.71	3.05	2.27
$\bar{P}$	24.47	16.76	12.43	8.56	6.67	4.84	3.31	2.33
$\%\sigma_P$	1.82	3.73	4.08	5.00	0.56	5.36	4.76	3.18
$\%\sigma_{\bar{P}}$	0.69	1.52	1.54	1.89	0.23	2.03	1.80	1.30

TABLE 2, Cont'd

Peak Pressure - TNETB in Free Air

Shot# \ λ	5.70	6.70	7.70	8.95	10.70	12.95	16.20	20.70
10WO-24	25.24	16.97	13.45	9.49	7.02	5.19	3.52	2.57
28	24.84	17.22	13.79	10.11	7.09	5.33	3.81	2.52
31	26.01	18.50	12.79	9.81	7.25	5.13	3.52	2.53
45	25.00	16.81	13.21	9.24	----	----	3.63	2.34
49	26.49	18.57	12.98	9.15	6.77	5.12	3.67	2.37
69	25.79	17.57	12.72	9.27	7.23	5.29	3.40	2.43
$\bar{P}$	25.56	17.61	13.16	9.51	7.07	5.21	3.59	2.46
$\%\sigma_{P}$	2.51	4.33	3.12	3.98	2.73	1.80	3.94	3.74
$\%\sigma_{\bar{P}}$	1.02	1.77	1.28	1.62	1.22	0.81	1.61	1.53

Peak Pressure - TNETB in N_2 (from Phase I (Reference (1))

Shot# \ λ	5.87	6.90	7.93	9.22	11.02	13.34	16.69	21.32
10WO-23	21.73	15.83	11.51	8.50	6.34	4.57	3.33	2.22
32	19.54	16.13	11.57	8.17	6.07	4.61	3.24	2.10
47	28.02	17.07	13.04	9.18	6.92	4.81	3.28	2.22
87	23.69	15.81	10.81	8.32	5.81	4.25	3.00	2.04
$\bar{P}$	23.24	16.21	11.73	8.54	6.28	4.56	3.21	2.14
$\%\sigma_{P}$	15.5	3.6	8.0	5.2	7.6	5.1	4.5	4.2
$\%\sigma_{\bar{P}}$	7.8	1.8	4.0	2.6	3.8	2.5	2.3	2.1

TABLE 2, Cont'd

Peak Pressure -- TNETB/Al, 90/10 in Free Air

Shot# \ λ	5.61	6.60	7.58	8.81	10.54	12.75	15.95	20.39
10WO-20	27.89	20.04	16.02	10.48	7.48	5.35	3.74	2.59
25	27.17	17.93	13.53	10.32	7.60	5.60	3.92	2.84
37	27.30	19.25	15.10	10.38	7.99	5.62	3.88	2.91
42	*30.28	16.96	13.74	10.02	*6.93	5.46	3.78	2.66
47	28.67	19.95	14.25	*11.15	7.95	----	----	2.75
70	28.06	19.21	14.82	10.20	7.91	5.63	3.64	2.59
$\bar{P}$	27.82	18.89	14.58	10.28	7.79	5.53	3.79	2.72
$\%\sigma_P$	2.18	6.40	6.37	1.74	2.93	2.21	2.99	4.90
$\%\sigma_{\bar{P}}$	0.98	2.61	2.60	0.78	1.31	0.99	1.34	2.00

Peak Pressure - TNETB/Al, 90/10 in N_2

Shot# \ λ	5.61	6.60	7.58	8.81	10.54	12.75	15.95	20.39
10WO-15	*28.38	18.26	14.14	9.97	7.78	5.68	3.76	2.66
18	26.81	18.25	13.56	9.15	7.56	5.20	3.52	2.60
23	26.49	18.10	14.78	10.51	7.54	5.52	3.81	2.89
39	26.85	17.97	13.84	9.98	7.50	5.36	3.71	2.66
48	26.52	16.75	14.09	9.66	7.19	5.05	3.56	2.53
71	26.15	16.53	12.97	9.44	7.29	5.22	3.62	2.44
$\bar{P}$	26.57	17.64	13.89	9.79	7.48	5.34	3.66	2.63
$\%\sigma_P$	1.06	4.46	4.39	4.88	2.82	4.28	3.06	5.76
$\%\sigma_{\bar{P}}$	0.48	1.82	1.79	1.99	1.15	1.75	1.25	2.35

TABLE 2, Cont'd

Peak Pressure - TNETB/Al, 72/28 in Free Air

Shot# \ λ	5.43	6.38	7.33	8.52	10.19	12.33	15.43	19.72
10WO-8	30.51	18.77	13.62	*9.45	7.75	5.36	3.87	2.73
10	29.08	19.89	15.28	10.79	8.26	5.79	3.84	2.69
27	28.17	19.23	15.32	11.27	8.09	5.71	4.05	2.91
30	26.04	18.53	13.92	10.46	7.81	5.58	3.93	2.88
40	26.58	20.12	15.60	11.30	8.51	5.68	4.17	2.94
50	26.82	19.35	14.39	10.53	7.68	5.55	3.92	3.06
$\bar{P}$	27.87	19.31	14.69	10.87	8.02	5.61	3.96	2.87
$\%\sigma_P$	6.14	3.21	5.63	3.66	4.07	2.68	3.13	4.86
$\%\sigma_{\bar{P}}$	2.51	1.31	2.30	1.64	1.66	1.09	1.28	1.98

Peak Pressure - TNETB/Al, 72/28 in N_2

Shot# \ λ	5.43	6.38	7.33	8.52	10.19	12.33	15.43	19.72
10WO-7	27.64	17.55	13.37	9.26	7.78	5.41	3.67	2.56
11	26.27	17.21	12.55	9.41	7.23	5.35	*3.47	2.52
38	26.82	20.12	14.85	10.15	7.38	5.40	3.85	2.70
46	28.61	19.93	15.25	10.22	7.72	5.60	3.92	2.77
52	25.71	16.82	-----	-----	----	5.22	3.77	2.59
54	28.28	19.34	14.70	10.51	8.01	5.47	3.77	2.66
56	28.35	16.95	14.29	10.07	7.59	5.68	3.69	2.58
$\bar{P}$	27.38	18.27	14.17	9.94	7.62	5.45	3.78	2.63
$\%\sigma_P$	4.14	8.00	7.19	4.96	3.70	2.87	2.53	3.34
$\%\sigma_{\bar{P}}$	1.56	3.02	2.94	2.02	1.51	1.08	1.03	1.26

TABLE 2, Cont'd

Peak Pressure - RDX-wax/Al, 90/10 in Free Air

Shot# \ λ	5.76	6.77	7.78	9.05	10.82	13.09	16.38	20.93
10WO-16	26.43	18.43	14.26	9.45	7.46	*4.96	3.68	*2.48
29	26.66	18.57	13.79	9.96	6.97	5.32	3.85	2.72
32	27.85	*19.66	14.65	10.71	7.94	5.51	3.78	2.73
34	27.03	18.74	13.87	9.93	7.61	5.34	3.79	2.75
35	27.48	19.09	14.30	10.05	7.45	5.50	3.88	2.69
61	26.79	18.36	15.12	10.47	7.82	5.34	3.62	2.78
$\bar{P}$	27.04	18.64	14.33	10.10	7.54	5.40	3.77	2.73
$\%\sigma_P$	1.97	1.57	3.48	4.38	4.52	1.76	2.64	1.21
$\%\sigma_{\bar{P}}$	0.80	0.70	1.42	1.79	1.85	0.79	1.08	0.54

Peak Pressure - RDX-wax/Al, 90/10 in N_2

Shot# \ λ	5.76	6.77	7.78	9.05	10.82	13.09	16.38	20.93
10WO-21	24.05	16.54	12.38	8.86	6.69	4.98	3.29	2.36
22	23.77	16.31	12.36	8.97	6.54	4.80	3.19	2.38
26	21.17	*14.61	11.45	8.75	5.99	4.76	3.41	2.55
33	25.33	17.14	14.47	9.75	7.64	5.20	3.42	2.50
35	25.97	16.57	-----	-----	-----	5.06	3.39	2.54
$\bar{P}$	24.06	16.64	12.67	9.08	6.72	4.96	3.34	2.46
$\%\sigma_P$	7.69	2.12	10.10	4.99	10.17	3.66	2.96	3.71
$\%\sigma_{\bar{P}}$	3.44	1.06	5.05	2.49	5.08	1.64	1.32	1.66

TABLE 2, Cont'd

Peak Pressure - RDX-wax/Al, 80/20 in Free Air

Shot# \ λ	5.75	6.75	7.76	9.02	10.78	13.05	16.33	20.86
10WO-6	27.64	19.86	13.76	*9.63	7.67	5.59	3.98	2.64
43	30.01	18.37	13.10	10.28	7.83	5.70	3.87	2.85
44	27.88	17.83	14.12	10.44	*8.07	5.76	4.01	2.89
53	29.47	19.81	15.15	10.56	7.85	5.45	3.87	2.69
65	26.84	18.59	13.37	10.34	7.71	5.73	3.76	2.73
68	28.16	19.54	15.51	10.17	7.70	5.60	3.57	2.44
$\bar{P}$	28.33	19.00	14.17	10.36	7.76	5.64	3.84	2.71
$\%\sigma_P$	4.19	4.49	6.84	1.44	1.05	2.03	4.23	5.97
$\%\sigma_{\bar{P}}$	1.71	1.83	2.79	0.64	0.47	0.83	1.73	2.44

Peak Pressure - RDX-wax/Al, 80/20 in N_2

Shot# \ λ	5.75	6.75	7.76	9.02	10.78	13.05	16.33	20.86
10WO-13	----	----	----	9.67	6.67	5.15	3.31	2.52
17	26.55	18.55	13.64	9.39	7.59	5.41	3.72	2.32
36	29.84	19.64	14.64	9.87	6.89	4.97	3.46	2.30
41	25.99	18.41	12.49	9.79	7.13	5.15	3.66	2.53
51	26.83	18.64	14.38	9.60	7.14	5.16	3.70	2.58
$\bar{P}$	27.30	18.81	13.79	9.66	7.08	5.17	3.57	2.45
$\%\sigma_P$	6.33	2.98	6.99	1.93	4.81	3.04	4.97	5.33
$\%\sigma_{\bar{P}}$	3.17	1.49	3.50	0.86	2.15	1.36	2.22	2.38

TABLES 3 and 4

POSITIVE IMPULSE RESULTS

Notes common to all explosive mixtures in this table:

1. Impulse data are in psi-ms.
2. $\bar{I}$ = Mean Positive Impulse (psi-ms)
3. $\bar{a}$ = Mean Scaled Positive Impulse, $I/W^{1/3}$ (psi-ms/$lb^{1/3}$).
4. $\%\sigma_a$ = Standard Deviation in Per Cent.
5. $\%\sigma_{\bar{a}}$ = Standard Error in Per Cent.
6. * Indicates data discarded in accordance with Chauvenet's Criterion.
7. λ = Scaled Distance, $d/W^{1/3}$ (ft/$lb^{1/3}$).

TABLE 3

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - PENTOLITE

FREE AIR

Shot# \ λ	7.55	8.77	10.49	12.70
10WO-1	8.47	7.67	5.61	5.48
	8.05	7.42	6.14	4.97
2	----	----	5.95	5.43
	----	----	5.94	----
3	8.46	8.14	6.52	5.54
	8.26	7.70	5.89	5.10
4	8.35	7.76	5.65	5.00
	8.26	7.72	5.86	4.90
9	----	7.50	6.29	5.41
	8.74	8.22	5.85	5.58
12	*12.01	----	5.57	4.50
	* 9.12	7.74	6.31	*3.78
$\bar{I}$	8.37	7.74	5.97	5.19
$\bar{a}$	8.21	7.59	5.85	5.09
$\%\sigma_a$	2.5	3.4	5.0	6.7
$\%\sigma_{\bar{a}}$	0.9	1.1	1.5	2.1

N_2

Shot# \ λ	7.55	8.77	10.49	12.70
10WO-58	6.75	6.39	5.63	3.55
	7.15	6.70	5.25	4.00
59	7.79	6.23	5.13	3.70
	7.55	6.08	5.36	3.91
60	7.04	6.28	4.57	3.32
	6.50	*5.00	5.15	3.67
62	6.74	5.86	4.62	3.74
	6.19	5.66	5.12	4.00
64	7.09	6.22	5.62	3.93
	7.02	6.90	*6.49	4.00
66	6.75	6.22	4.83	3.75
	6.74	5.94	4.88	3.77
67	6.66	5.82	4.57	3.57
	6.08	5.62	4.57	3.63
$\bar{I}$	6.86	6.15	5.02	3.75
$\bar{a}$	6.72	6.02	4.92	3.67
$\%\sigma_a$	6.7	6.2	7.6	5.3
$\%\sigma_{\bar{a}}$	1.8	1.7	2.1	1.4

TABLE 3 (Cont'd)

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - TNETB

FREE AIR

Shot# \ λ	7.70	8.95	10.70	12.95
10WO-24	7.98	7.15	5.33	4.69
	8.15	6.57	5.39	4.52
28	8.13	7.27	5.36	5.17
	8.18	6.93	5.63	5.36
31	----	6.69	5.38	4.66
	----	5.88	5.45	4.58
45	6.17	4.96	4.73	3.45
	5.85	5.21	4.74	3.64
49	7.70	6.12	5.50	3.85
	6.71	6.23	5.69	4.24
69	7.27	5.69	5.15	4.28
	7.08	6.05	5.40	4.19
$\bar{I}$	7.32	6.23	5.31	4.39
$\bar{a}$	7.32	6.23	5.31	4.39
$\%\sigma_a$	11.7	11.7	5.6	13.0
$\%\sigma_{\bar{a}}$	3.7	3.4	1.6	3.7

N_2 (Reference (1))

Shot# \ λ	7.93	9.22	11.02	13.34
10WO-23	----	6.26	5.72	4.32
	6.64	----	5.95	3.67
32	6.48	6.04	4.35	3.57
	6.61	5.50	4.51	3.37
47	6.37	6.38	4.73	----
	6.53	----	5.28	4.36
$\bar{I}$	6.53	6.04	5.09	3.86
$\bar{a}$	6.73	6.22	5.24	3.98
$\%\sigma_a$	1.6	6.5	13.0	11.7
$\%\sigma_{\bar{a}}$	0.74	3.2	5.3	5.2

(1) Secondary Shock is completely in negative phase and plays no part in positive impulse determinations

TABLE 3 (Cont'd)

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - TNETB/Al, 90/10

FREE AIR

Shot# \ λ	7.59	8.82	10.54	12.76
10WO-20	9.64	*9.95	5.23	4.57
	9.76	7.34	5.75	5.19
25	8.64	8.10	5.68	5.34
	8.73	7.01	5.68	5.23
37	9.75	7.76	5.96	----
	8.79	7.32	----	5.56
42	9.22	7.33	6.00	4.78
	8.91	7.92	----	5.18
47	8.76	7.13	5.98	4.61
	7.99	7.10	6.35	4.91
70	9.26	7.59	5.91	4.69
	8.02	7.37	6.50	4.70
$\bar{I}$	8.96	7.49	5.90	4.98
$\bar{a}$	8.83	7.38	5.81	4.91
$\%\sigma_a$	6.7	4.8	5.9	6.8
$\%\sigma_{\bar{a}}$	1.9	1.4	1.9	2.0

N_2

Shot# \ λ	7.59	8.82	10.54	12.76
10WO-15	8.37	7.46	5.88	5.18
	7.86	7.16	5.90	4.58
18	8.71	7.01	5.36	4.88
	7.11	6.04	5.48	4.67
23	8.60	----	5.98	5.06
	7.61	7.24	5.97	4.80
39	8.04	7.20	----	4.83
	7.35	6.99	6.31	4.86
48	7.61	5.78	5.77	----
	7.07	5.80	5.77	4.60
71	7.32	6.54	5.89	4.57
	6.29	6.27	6.06	4.69
$\bar{I}$	7.66	6.68	5.85	4.79
$\bar{a}$	7.55	6.58	5.76	4.72
$\%\sigma_a$	9.1	9.3	4.4	4.2
$\%\sigma_{\bar{a}}$	2.6	2.8	1.3	1.3

TABLE 3 (Cont'd)

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - TNETB/A1, 72/28

FREE AIR

Shot# \ λ	7.33	8.52	10.19	12.33
10WO-8	8.61	8.14	6.36	4.78
	9.07	----	6.71	5.41
10	----	8.40	6.54	----
	8.25	7.82	----	5.18
27	9.66	8.72	7.02	----
	9.66	8.60	----	6.32
30	9.95	8.98	6.92	5.84
	8.87	6.62	----	5.99
40	9.67	8.35	6.93	4.78
	8.99	8.23	*8.07	5.28
50	8.20	6.82	----	4.73
	8.78	7.98	6.82	5.00
$\bar{I}$	9.06	8.06	6.76	5.33
$\bar{a}$	8.63	7.68	6.44	5.08
$\%\sigma_a$	6.6	9.2	3.6	10.5
$\%\sigma_{\bar{a}}$	2.0	2.8	1.4	3.3

N_2

Shot# \ λ	7.33	8.52	10.19	12.33
10WO-7	----	----	6.19	5.13
	----	----	6.07	----
11	7.96	6.97	5.37	4.65
	8.84	6.75	5.44	4.70
38	9.09	8.20	5.69	4.35
	8.89	8.27	6.47	5.18
54	8.49	7.15	5.69	4.45
	6.86	6.72	6.96	4.46
56	8.25	6.61	----	4.38
	6.87	6.69	6.71	4.71
$\bar{I}$	8.16	7.17	6.07	4.57
$\bar{a}$	7.77	6.83	5.78	4.45
$\%\sigma_a$	10.8	9.5	9.2	7.0
$\%\sigma_{\bar{a}}$	3.8	3.4	3.1	2.3

TABLE 3 (Cont'd)

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - RDX-wax/Al, 90/10

FREE AIR

Shot# \ λ	7.78	9.05	10.82	13.09
10WO-16	9.29	8.17	5.79	5.10
	8.78	7.57	6.04	5.34
29	9.20	7.94	5.74	4.98
	8.88	6.92	5.63	5.34
32	9.47	8.34	6.08	5.33
	*9.68	7.49	6.19	*5.77
34	9.13	7.90	5.77	5.40
	9.12	7.24	5.79	5.54
35	9.10	7.63	6.42	5.12
	9.15	7.90	6.40	5.28
61	9.20	7.29	6.23	5.24
	8.88	7.75	6.38	5.29
$\bar{I}$	9.11	7.68	6.04	5.27
$\bar{a}$	9.21	7.76	6.11	5.33
$\%\sigma_a$	2.2	5.3	4.8	2.8
$\%\sigma_{\bar{a}}$	0.7	1.5	1.4	0.8

N_2

Shot# \ λ	7.78	9.05	10.82	13.09
10WO-21	8.18	6.99	4.93	4.31
	7.75	5.98	5.08	4.47
22	7.62	7.05	4.96	4.31
	7.84	6.29	5.05	4.30
26	7.72	6.30	4.96	3.82
	7.47	6.10	5.05	4.10
33	7.60	6.61	4.97	4.46
	7.14	6.45	5.14	4.36
55	7.58	5.89	----	3.83
	7.05	5.87	5.18	3.86
$\bar{I}$	7.60	6.35	5.04	4.18
$\bar{a}$	7.68	6.42	5.10	4.23
$\%\sigma_a$	4.3	6.6	1.8	6.2
$\%\sigma_{\bar{a}}$	1.4	2.1	0.6	2.0

TABLE 3 (Cont'd)

POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK) - RDX-wax/Al, 80/20

FREE AIR

Shot# \ λ	7.76	9.02	10.79	13.05
10WO-6	9.07	7.14	6.44	5.04
	8.89	7.36	6.81	5.43
43	9.05	7.84	6.93	----
	8.40	7.51	----	5.36
44	9.48	7.67	6.07	5.53
	8.33	7.41	7.09	5.53
53	8.96	7.60	6.69	4.80
	8.67	8.24	7.09	4.73
65	8.75	8.05	6.63	4.97
	9.51	7.47	7.07	5.28
68	8.33	8.04	5.89	4.98
	8.95	8.11	7.76	5.05
$\bar{I}$	8.87	7.70	6.77	5.15
$\bar{a}$	8.94	7.76	6.82	5.19
$\%\sigma_a$	4.5	4.5	7.6	5.4
$\%\sigma_{\bar{a}}$	1.3	1.3	2.3	1.6

N_2

Shot# \ λ	7.76	9.02	10.79	13.05
10WO-13	8.64	6.72	6.08	4.43
	----	7.01	6.03	4.46
17	8.40	7.28	5.53	4.66
	8.33	6.24	5.31	4.56
36	8.70	6.83	5.17	4.36
	8.23	6.95	5.76	4.35
41	8.15	6.30	5.51	----
	7.36	6.29	6.10	----
51	----	6.20	----	4.03
	7.54	7.38	6.58	4.18
$\bar{I}$	8.17	6.72	5.79	4.38
$\bar{a}$	8.24	6.77	5.84	4.42
$\%\sigma_a$	5.9	6.5	7.8	4.6
$\%\sigma_{\bar{a}}$	2.1	2.1	2.6	1.6

TABLE 4

POSITIVE IMPULSE RESULTS (EXCLUDING SECONDARY SHOCK)

Notes common to all explosive mixtures in this table:

See TABLE III for definition of symbols.

TABLE 4

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - PENTOLITE

FREE AIR

Shot# \ λ	7.55	8.77	10.49	12.70
10WO-1	7.93	7.14	5.38	4.91
	7.72	6.88	5.75	4.71
2	----	----	5.60	4.84
	----	----	5.56	----
3	8.00	7.50	6.01	5.13
	7.94	7.06	5.56	4.58
4	8.35	7.30	5.45	4.69
	8.11	7.03	5.49	4.61
9	----	7.11	6.08	4.92
	7.98	7.55	5.80	5.04
12	*9.32	----	5.40	4.16
	8.38	7.25	5.90	*3.60
$\bar{I}$	8.05	7.20	5.67	4.76
$\bar{a}$	7.89	7.06	5.56	4.67
$\%\sigma_a$	2.7	3.1	4.2	5.9
$\%\sigma_{\bar{a}}$	1.0	1.0	1.2	1.9

N_2

Shot# \ λ	7.55	8.77	10.49	12.70
10WO-58	6.75	6.39	5.63	3.55
	7.15	6.70	5.25	4.00
59	7.63	6.23	5.13	3.70
	7.53	6.08	5.36	3.91
60	7.04	6.28	4.57	3.32
	6.50	*5.00	5.15	3.67
62	6.74	5.86	4.62	3.69
	6.18	5.66	5.10	3.98
64	7.09	6.22	5.45	3.90
	7.02	6.75	*6.29	3.98
66	6.75	6.22	4.83	3.75
	6.74	5.94	4.88	3.77
67	6.66	5.82	4.57	3.57
	6.08	5.62	4.57	3.63
$\bar{I}$	6.85	6.14	5.01	3.74
$\bar{a}$	6.72	6.02	4.91	3.67
$\%\sigma_a$	6.4	5.9	7.2	5.3
$\%\sigma_{\bar{a}}$	1.7	1.6	2.0	1.4

TABLE 4, (Cont'd)

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - TNETB

FREE AIR

Shot# \ λ	7.70	8.95	10.70	12.95
10WO-24	7.92	7.03	5.33	4.69
	7.95	6.57	5.39	4.47
28	7.95	7.09	5.36	5.17
	7.67	6.93	5.60	5.30
31	----	6.67	5.38	4.66
	----	5.88	5.45	4.54
45	5.99	4.93	4.62	3.42
	5.81	5.01	4.74	3.64
49	7.53	6.01	5.26	3.85
	6.71	6.08	5.69	4.24
69	7.16	5.69	5.13	4.28
	7.08	6.05	5.40	4.19
$\bar{I}$	7.18	6.16	5.28	4.37
$\bar{a}$	7.18	6.16	5.28	4.37
$\%\sigma_a$	11.0	11.8	6.1	12.8
$\%\sigma_{\bar{a}}$	3.5	3.4	1.7	3.7

TABLE 4 (Cont'd)

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - TNETB/Al, 90/10

FREE AIR

Shot# \ λ	7.59	8.82	10.54	12.76
10WO-20	9.14	*8.83	5.23	4.56
	9.02	7.29	5.71	4.90
25	8.39	7.39	5.66	5.12
	8.43	6.99	5.67	5.11
37	9.02	7.45	5.83	----
	8.66	7.25	----	5.28
42	8.78	7.41	5.64	4.64
	8.40	7.41	----	4.91
47	8.35	7.12	5.95	4.61
	7.73	7.01	6.34	4.86
70	8.94	7.46	5.91	4.64
	7.85	7.08	6.42	4.66
$\bar{I}$	8.56	7.26	5.84	4.84
$\bar{a}$	8.43	7.15	5.75	4.77
$\%\sigma_a$	5.3	2.5	6.0	5.0
$\%\sigma_{\bar{a}}$	1.5	0.8	1.9	1.5

N_2

Shot# \ λ	7.59	8.82	10.54	12.76
10WO-15	8.29	7.32	5.59	5.01
	7.86	7.16	5.80	4.58
18	8.59	6.76	5.36	4.88
	7.11	6.04	5.48	4.61
23	8.59	----	5.98	5.07
	7.61	7.24	5.97	4.78
39	8.03	7.20	----	4.83
	7.35	6.99	6.08	4.84
48	7.61	5.78	5.77	----
	7.07	5.78	5.77	4.48
71	7.31	6.54	5.82	4.57
	6.29	6.19	6.06	4.68
$\bar{I}$	7.64	6.64	5.79	4.76
$\bar{a}$	7.53	6.54	5.70	4.69
$\%\sigma_a$	8.9	9.0	4.0	4.0
$\%\sigma_{\bar{a}}$	2.6	2.7	1.2	1.2

TABLE 4 (Cont'd)

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - TNETB/Al, 72/28

FREE AIR

Shot# \ λ	7.33	8.52	10.19	12.33
10WO-8	8.10	7.64	5.87	4.65
	8.01	----	5.98	4.90
10	----	7.98	6.42	----
	8.15	7.54	----	5.04
27	8.77	8.02	6.53	----
	8.77	8.06	----	5.72
30	8.92	8.06	6.39	5.35
	8.26	*6.58	----	5.41
40	9.03	7.85	6.58	4.68
	8.60	7.88	*7.21	5.09
50	8.20	*6.75	----	4.60
	8.53	7.98	6.52	4.77
$\bar{I}$	8.49	7.89	6.33	5.02
$\bar{a}$	8.09	7.51	6.03	4.78
$\%\sigma_a$	4.2	2.4	4.4	7.4
$\%\sigma_{\bar{a}}$	1.3	0.8	1.7	2.3

N_2

Shot# \ λ	7.33	8.52	10.19	12.33
10WO-7	----	----	5.61	5.02
	----	----	5.76	----
11	7.37	6.74	5.32	4.51
	7.62	6.57	5.33	4.56
38	8.60	7.85	5.59	4.31
	8.74	7.92	6.40	5.03
54	8.39	7.15	5.69	4.45
	6.84	6.70	6.96	4.44
56	8.25	6.61	----	4.38
	6.87	6.69	6.71	4.71
$\bar{I}$	7.84	7.03	5.93	4.60
$\bar{a}$	7.47	6.70	5.65	4.38
$\%\sigma_a$	9.7	8.0	10.1	5.9
$\%\sigma_{\bar{a}}$	3.4	2.8	3.4	2.0

TABLE 4 (Cont'd)

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - RDX-wax/Al, 90/10

FREE AIR

Shot# \ λ	7.78	9.05	10.82	13.09
10WO-16	8.44	7.39	5.42	4.72
	8.00	7.20	5.76	4.86
29	8.31	7.27	5.47	*5.36
	8.00	6.84	5.36	4.78
32	8.47	7.52	5.79	4.96
	8.36	7.18	5.78	5.12
34	8.17	7.22	5.52	4.89
	8.18	6.91	5.39	5.01
35	8.60	7.27	6.06	4.75
	8.34	7.35	6.04	4.78
61	8.52	7.01	5.92	4.90
	8.42	7.20	6.00	4.94
$\bar{I}$	8.32	7.20	5.71	4.88
$\bar{a}$	8.41	7.28	5.77	4.93
$\%\sigma_a$	2.3	2.8	4.7	2.5
$\%\sigma_{\bar{a}}$	0.7	0.8	1.4	0.7

N_2

Shot# \ λ	7.78	9.05	10.82	13.09
10WO-21	7.56	6.76	4.93	4.31
	7.33	5.98	5.07	4.43
22	7.51	6.54	4.96	4.31
	7.58	6.29	5.05	4.30
26	7.55	6.18	4.96	3.82
	7.47	6.10	5.04	4.10
33	7.59	6.61	4.97	4.46
	7.14	6.45	5.14	4.33
55	7.58	5.89	----	3.83
	7.05	5.87	5.10	3.86
$\bar{I}$	7.44	6.27	5.02	4.18
$\bar{a}$	7.52	6.34	5.08	4.23
$\%\sigma_a$	2.7	4.9	1.4	6.0
$\%\sigma_{\bar{a}}$	0.9	1.5	0.5	1.9

TABLE 4 (Cont'd)

POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK) - RDX-wax/Al, 80/20

FREE AIR

Shot# \ λ	7.76	9.02	10.79	13.05
10WO-6	8.29	6.82	5.86	4.79
	8.33	6.53	6.11	5.00
43	8.50	7.10	6.31	----
	7.83	6.62	----	5.12
44	8.55	7.10	5.83	4.95
	7.96	7.09	6.39	5.16
53	8.21	7.60	6.23	4.44
	8.04	7.63	6.39	4.44
65	8.23	7.36	6.23	4.74
	8.55	7.47	6.32	4.92
68	8.31	7.43	5.72	4.56
	8.34	7.42	6.70	4.75
$\bar{I}$	8.26	7.18	6.19	4.81
$\bar{a}$	8.33	7.24	6.24	4.85
$\%\sigma_a$	2.8	5.2	4.5	4.9
$\%\sigma_{\bar{a}}$	0.8	1.5	1.4	1.5

N_2

Shot# \ λ	7.76	9.02	10.79	13.05
10WO-13	8.13	6.72	5.64	4.30
	----	6.52	5.56	4.31
17	8.34	7.09	5.53	4.66
	8.02	6.24	5.31	4.56
36	8.54	6.78	5.17	4.31
	8.01	6.84	5.72	4.25
41	8.01	6.30	5.48	----
	7.36	6.29	5.87	----
51	----	6.20	----	4.03
	7.28	6.67	*6.35	4.15
$\bar{I}$	7.96	6.57	5.54	4.32
$\bar{a}$	8.02	6.62	5.58	4.35
$\%\sigma_a$	5.5	4.6	4.0	4.6
$\%\sigma_{\bar{a}}$	1.9	1.5	1.4	1.6

TABLE 5-A

EQUIVALENT WEIGHT RESULTS

Phase II Program

Nitrogen Atmosphere (4.5 Ft. Diam. Balloon)

Explosive Matrix	Percentage Composition	EW_P	EW_I	EW_{IX}
TNETB(1) (2)	100	1.00	1.00	1.00
TNETB/Al	90/10	1.03 ± 0.01(3)	1.11 ± 0.05	1.10 ± 0.05
TNETB/Al	72/28(5)	0.97 ± 0.01	1.06 ± 0.07	1.03 ± 0.07
RDX-wax(2)	98/2	0.86 ± 0.02	0.84 ± 0.05	0.84 ± 0.05
RDX-wax/Al	90/10	0.98 ± 0.01	1.05 ± 0.04	1.05 ± 0.05
RDX-wax/Al	80/20	1.08 ± 0.01	1.18 ± 0.06	1.13 ± 0.05
Pentolite	100	0.87 ± 0.01	0.90 ± 0.04	0.90 ± 0.04

Air Atmosphere

Explosive Matrix	Percentage Composition	EW_P	EW_I	EW_{IX}
TNETB(4)	100	1.02	1.03	1.02
TNETB/Al	90/10	1.11 ± 0.01	1.25 ± 0.06	1.21 ± 0.05
TNETB/Al	72/28 (5)	1.06 ± 0.02	1.24 ± 0.06	1.18 ± 0.05
RDX-wax(2)	98/2	1.07 ± 0.03	1.24 ± 0.06	1.11 ± 0.07
RDX-wax/Al	90/10	1.17 ± 0.01	1.41 ± 0.06	1.27 ± 0.06
RDX-wax/Al	80/20	1.19 ± 0.02	1.42 ± 0.07	1.30 ± 0.06
Pentolite	100	1.05 ± 0.02	1.23 ± 0.05	1.12 ± 0.05

(1) Standard, or reference explosive.

(2) Data from Phase I Program (reference 1).

(3) Precision indices are relative to TNETB, Air (Phase II Program) except for RDX-wax (100/2) which are relative to TNETB, N_2 (Phase I - reference 1).

(4) Control test: referenced to results for TNETB, Air series, from Phase I - (reference 1). Value of EW_{IX} changed (upon re-examination of the original data) to 1.02 rather than 1.03, the value reported in Phase I - (reference 1).

(5) Charges may have been inadequately initiated; see Section 3.1.

TABLE 5-B

EQUIVALENT WEIGHT RESULTS

Phase I Program - (Reference 1)

Explosive	Gas (& Balloon Diameter)	EW_P	EW_I	EW_{IX}
TNETB	N_2 (4.5')	1.00	1.00	1.00[1]
TNETB	Free Air	1.02± 0.03[2]	1.03± 0.06	1.02± 0.06[3]
TNETB[4]	O_2 (4.5')	1.02± 0.03	1.18± 0.07	1.08± 0.07
RDX[4]	N_2 (4.5')	0.86± 0.02	0.84± 0.05	0.84± 0.05
RDX[4]	Free Air	1.07± 0.03	1.24± 0.09	1.11± 0.07
[illegible]	O_2 (4.5')	1.13± 0.03	1.51± 0.10	1.19± 0.08
TNT	N_2 (4.5')	0.72± 0.02	0.70± 0.04	0.70± 0.04
TNT	Free Air	0.90± 0.01	1.07± 0.06	0.93± 0.05
TNT	O_2 (4.5')	0.99± 0.02	1.39± 0.09	1.15± 0.08
TNT	N_2 (3.0')	0.72 --	0.69 --	0.69 --
TNT	N_2 (1.5')	0.85± 0.02	0.91± 0.04	0.88± 0.04
Pentolite	Free Air	1.01 --	-- --	-- --
Pentolite	Air (4.5')	0.97± 0.014[5]	-- --	-- --

(1) $EW_{IX} = EW_I$ for N_2 series.

(2) Equivalent weight precision indices relative to TNETB in N_2.

(3) Value charged (upon re-examination of the original data) from the value, 1.03, reported in reference 1.

(4) 2% wax added.

(5) Precision index relative to Pentolite in free air.

TABLE 6

EQUIVALENT WEIGHT RESULTS (RELATIVE BASIS)
TABLE 6-A

Effect of Aluminum

(Aluminized EW Results Relative to Results For Zero Percent Aluminum)

Nitrogen Atmosphere (4.5 Ft. Diam. Balloon)

Explosive	Percent Aluminum	EW_P	EW_I	EW_{IX}
TNETB	0	1.00	1.00	1.00
TNETB	10	1.03	1.11	1.10
TNETB	28 (1)	0.97	1.06	1.03
RDX-wax	0	1.00	1.00	1.00
RDX-wax	10	1.14	1.25	1.25
RDX-wax	20	1.26	1.41	1.35

Free Air Atmosphere

TNETB	0	1.00	1.00	1.00
TNETB	10	1.09	1.21	1.19
TNETB	28 (1)	1.04	1.20	1.16
RDX-wax	0	1.00	1.00	1.00
RDX-wax	10	1.09	1.14	1.14
RDX-wax	20	1.11	1.16	1.16

(1) Charges may have been inadequately initiated; see Section 3.1.

TABLE 6-B

EFFECTS OF AMBIENT GAS

(Air Results Relative to Nitrogen Results, by Explosive)

Explosive	Percent Aluminum	EW_P Basis	EW_I Basis	EW_{IX} Basis
TNETB	0	1.02	1.03	1.02
TNETB	10	1.08	1.13	1.10
TNETB	28	1.09	1.17	1.08
RDX-wax	0	1.24	1.48	1.32
RDX-wax	10	1.19	1.34	1.21
RDX-wax	20	1.10	1.20	1.15
Pentolite	0	1.21	1.35	1.23
TNT	0	1.25	1.53	1.33

TABLE 6-C

EFFECT OF OXYGEN BALANCE (O.B.)

N_2: .. Results Vs Oxygen Balance (Relative to TNETB in N_2)

Explosive	Percent Aluminum	-O.B.	EW_P	EW_I	EW_{IX}
TNETB	0	0.04	1.00	1.00	1.00
TNETB	10	0.13	1.03	1.11	1.10
TNETB	28	0.28	0.97	1.06	1.03
RDX-wax	0	0.28	0.86	0.84	0.84
RDX-wax	10	0.34	0.98	1.05	1.05
RDX-wax	20	0.40	1.08	1.18	1.13
Pentolite	0	0.42	0.87	0.90	0.90
TNT	0	0.74	0.72	0.70	0.70

Air: EW Results Vs Oxygen Balance (Relative to TNETB in Free Air)

Explosive	Percent Aluminum	-O.B.	EW_P	EW_I	EW_{IX}
TNETB	0	0.04	1.00	1.00	1.00
TNETB	10	0.13	1.09	1.21	1.19
TNETB	28	0.28	1.04	1.20	1.16
RDX-wax	0	0.28	1.05	1.20	1.09
RDX-wax	10	0.34	1.15	1.37	1.24
RDX-wax	20	0.40	1.17	1.38	1.27
Pentolite	0	0.42	1.03	1.19	1.10
TNT	0	0.74	0.88	1.04	0.91

TABLE 6-D

EFFECT OF HEAT OF DETONATION, h_D,
ON EW_P AND EW_{IX} (NITROGEN RESULTS)

Explosive	Percent, Aluminum	h_D (Kcal/gm) (1)	EW_P	$\frac{EW_P}{h_D}$	EW_{IX}	$\frac{EW_{IX}}{h_D}$
TNETB	0	1.45	1.00	0.72	1.00	0.72
TNETB	10	1.63	1.03	0.63	1.10	0.68
TNETB	28	2.21	0.97	0.44	1.03	0.47
RDX-wax	0	1.20(1.32)(2)	0.86	0.72	0.84	0.70
RDX-wax	10	1.63(1.60)	0.98	0.60	1.05	0.64
RDX-wax	20	2.05(1.90)	1.08	0.53	1.13	0.55
Pentolite	0	1.20(3)	0.87	0.72	0.90	0.75
TNT	0	0.984(1.01)(2)	0.72	0.73	0.70	0.71

(1) Modified arbitrary water decomposition mechanism used; order of products assumed to be $Al_2O_3(\gamma)$, $H_2O(g)$, CO, CO_2.

(2) From Reference (9), experimental results.

(3) Components (TNT and PETN) assumed to detonate independently.

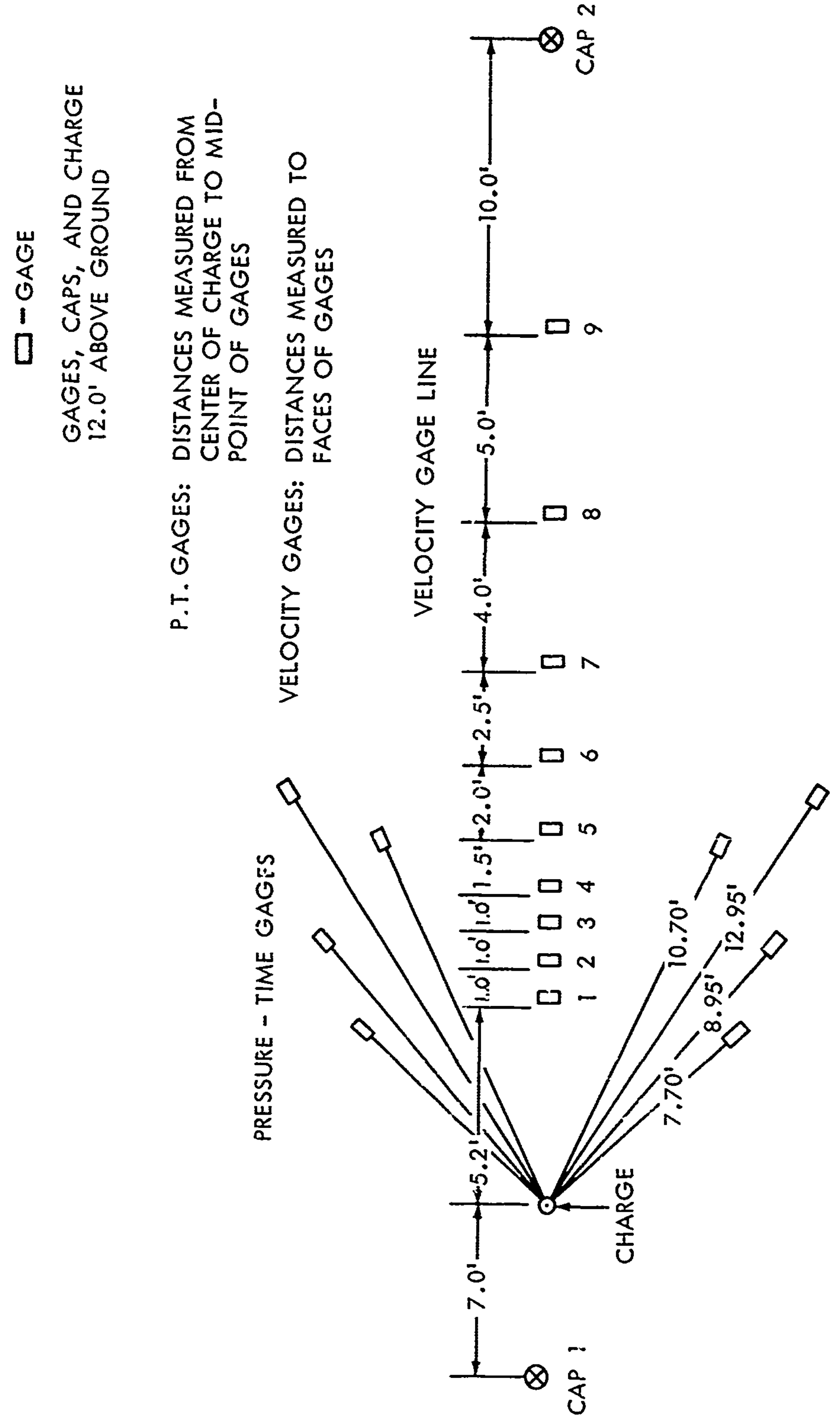
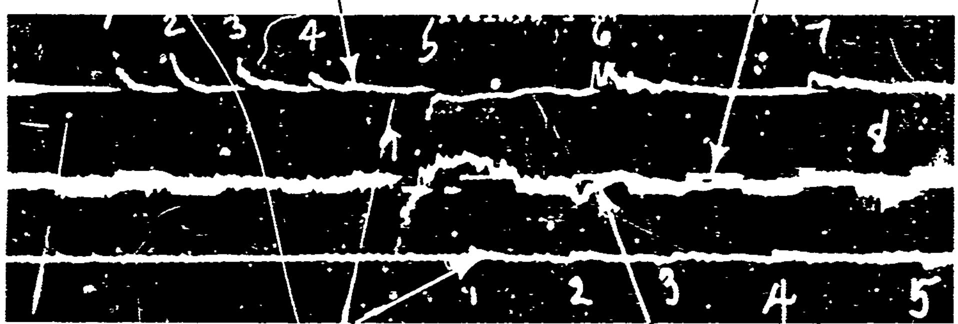


FIG. 1 PLAN VIEW OF EXPERIMENT SET-UP

SHOCK RECORD (MAIN CHARGE) MILLISECOND TIMING MARKS

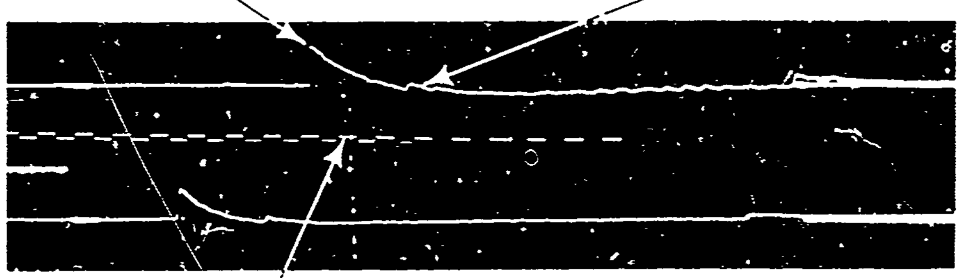


SOUND RECORD (CAP 1) SOUND RECORD (CAP 2)

(NUMBERS CORRESPOND TO VELOCITY-GAGE NUMBERS ON FIGURE 1 OF THIS REPORT)

A PORTION OF A VELOCITY RECORD

PRIMARY SHOCK SECONDARY SHOCK



ONE-MILLISECOND TIMING MARKS

PRESSURE-TIME RECORD

CHARGE COMPOSITION	RDX-WAX, Al, 80, 20
AMBIENT GAS	NITROGEN, IN 4.5-FT. DIAMETER BALLOON
CHARGE WEIGHT	0.98 LB.
PEAK PRESSURE	14.64 PSI
POSITIVE IMPULSE	8.54 PSI-MSEC
DISTANCE FROM CHARGE	[illegible] 76 FT.

FIG. 2 TYPICAL RECORDS

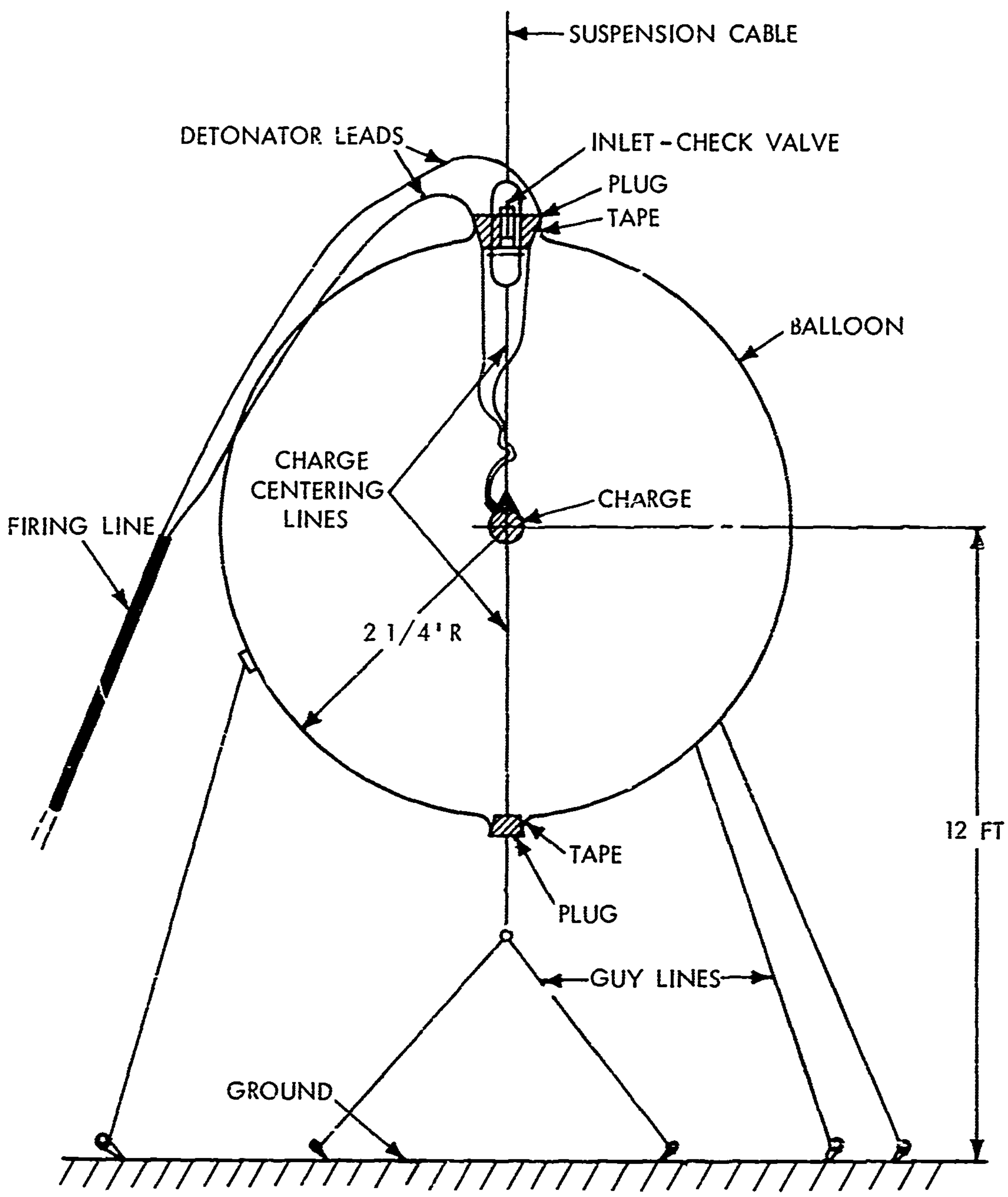


FIG. 3 CHARGE SUSPENSION USING BALLOON (SECTION VIEW)

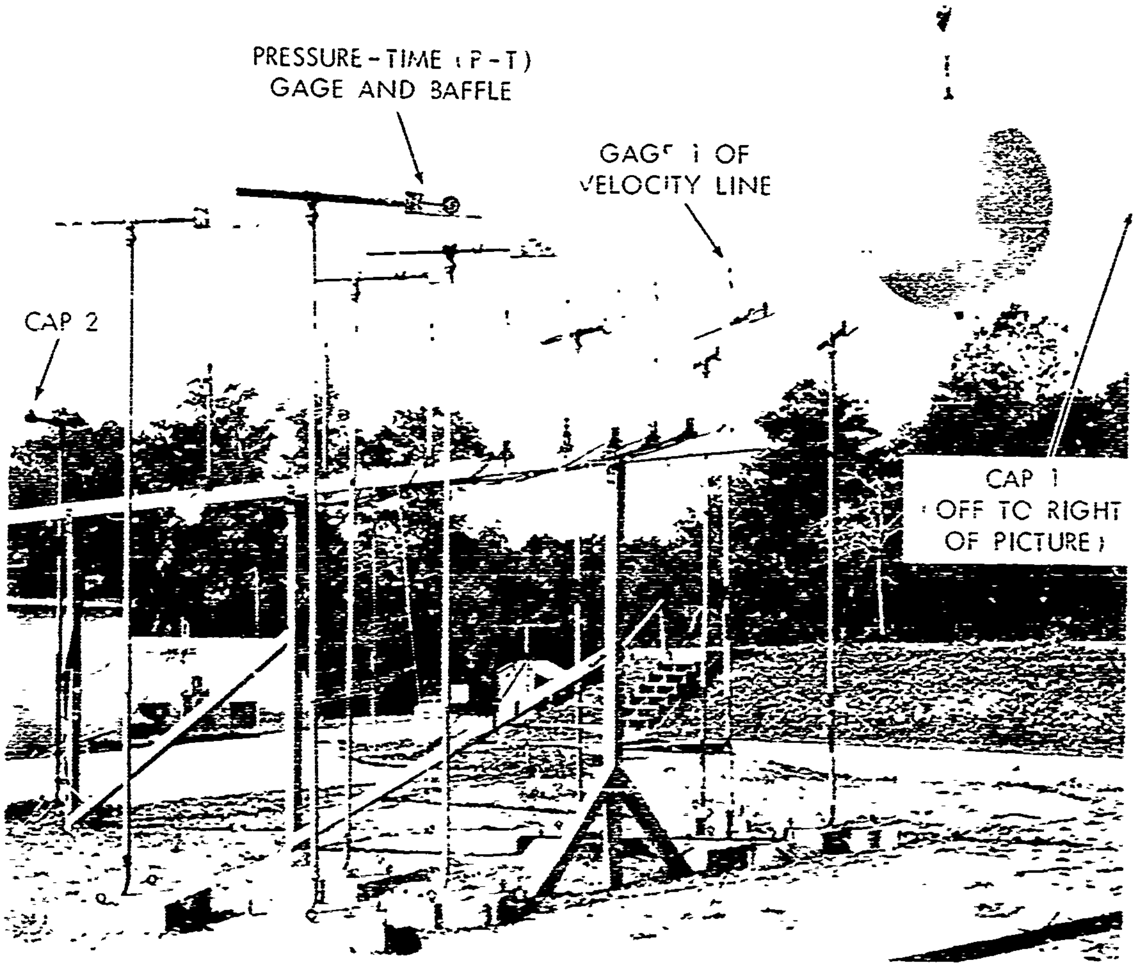


FIG. 4 TYPICAL FIELD ARRANGEMENT FOR BALLOON SHOT

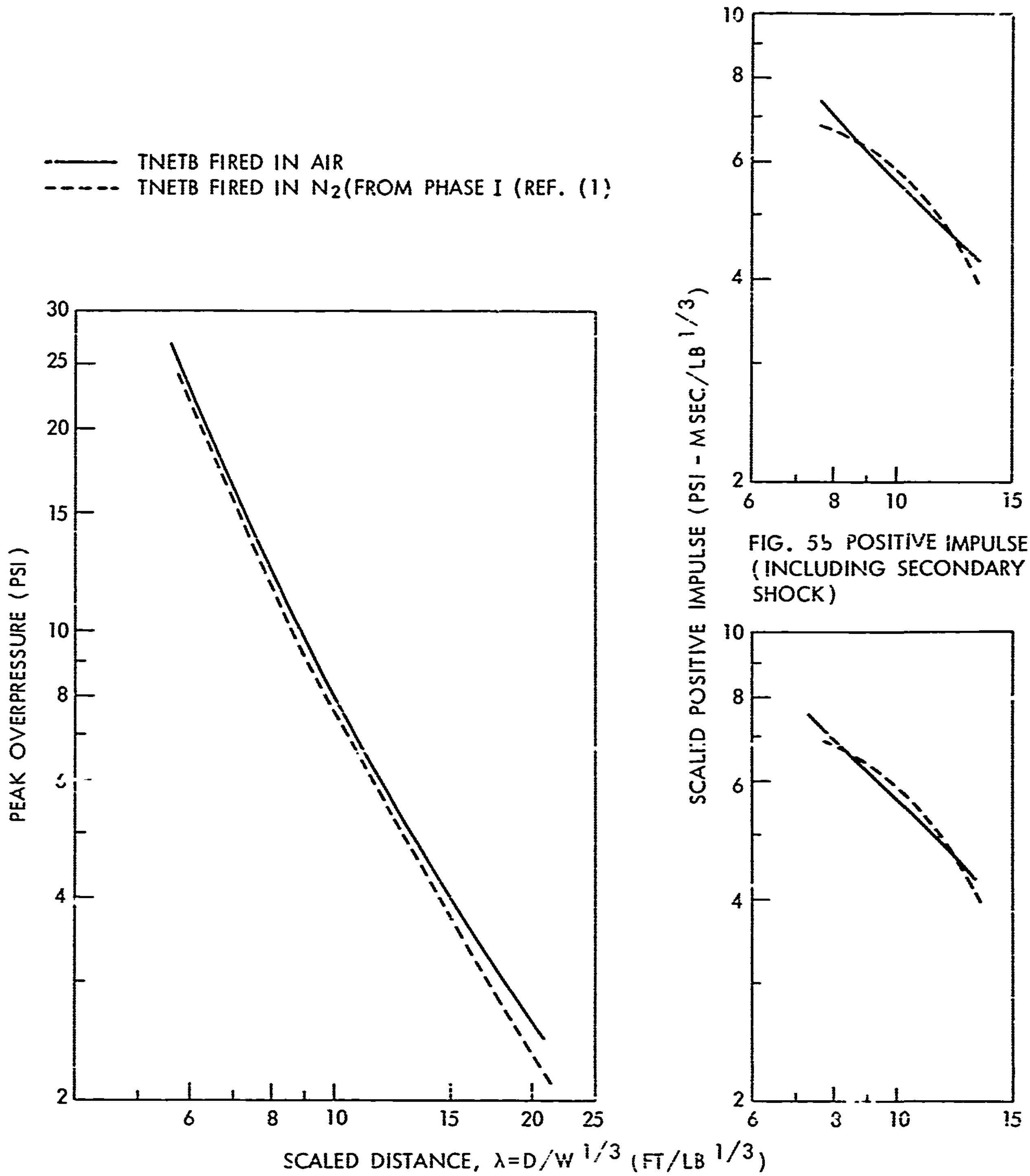


FIG. 5a PEAK OVERPRESSURE

FIG. 5c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 5 COMPARISON OF TNETB FIRED IN AIR AND N_2

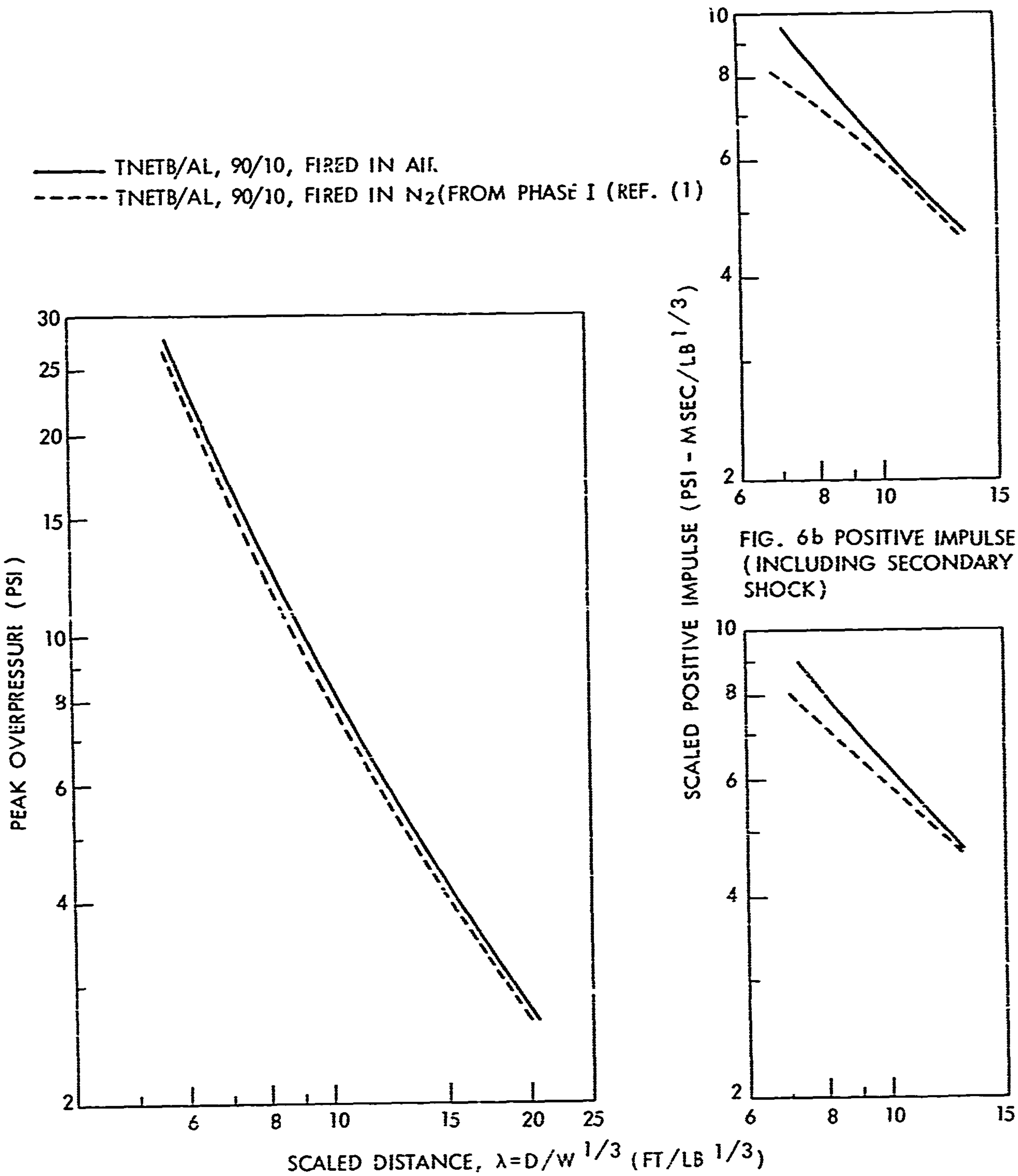


FIG. 6a PEAK OVERPRESSURE

FIG. 6b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 6c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 6 COMPARISON OF TNETB/AL, 90/10, FIRED IN AIR AND N_2

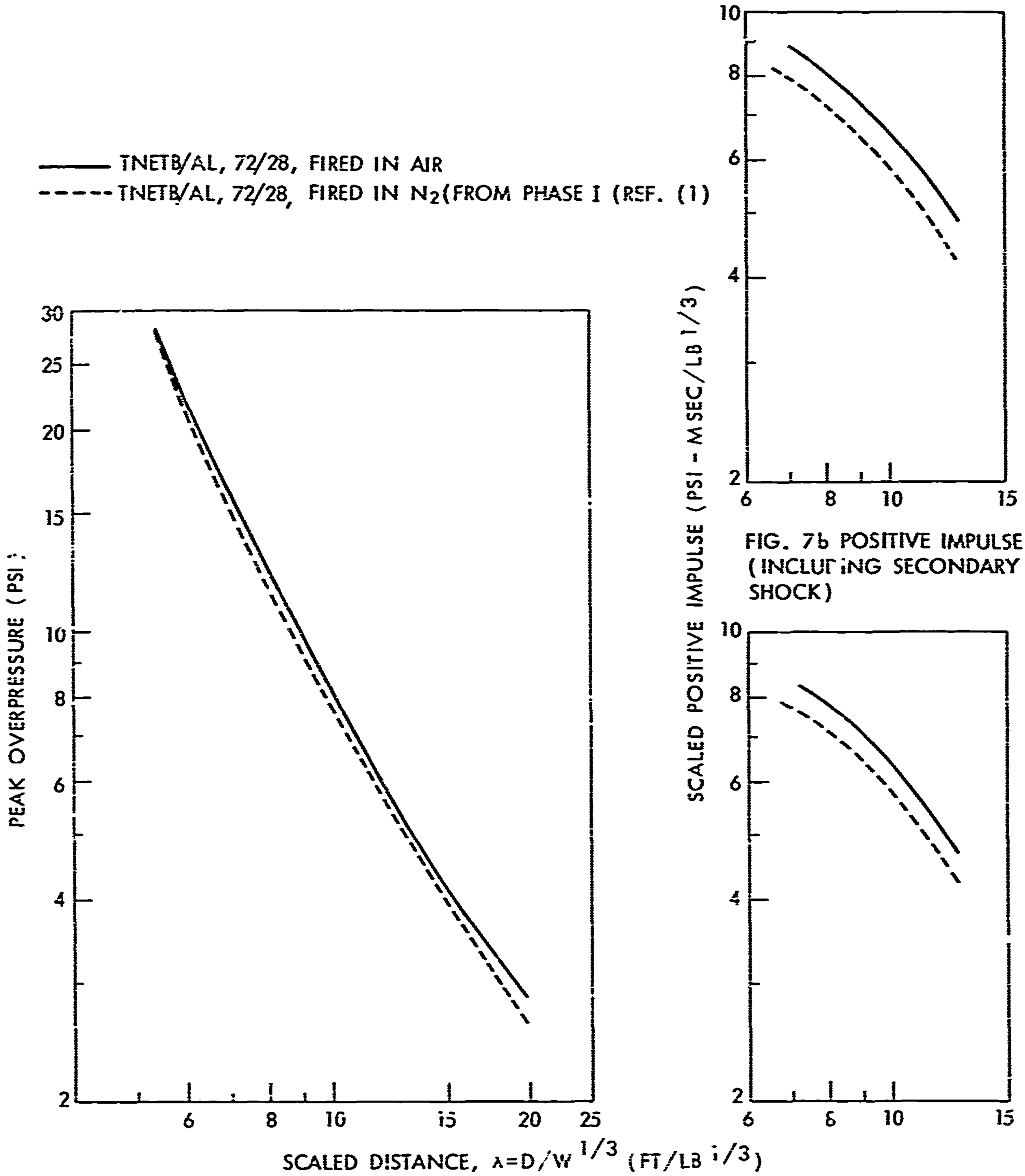


FIG. 7a PEAK OVERPRESSURE

FIG. 7b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 7c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 7 COMPARISON OF TNETB/AL, 72/28, FIRED IN AIR AND N_2

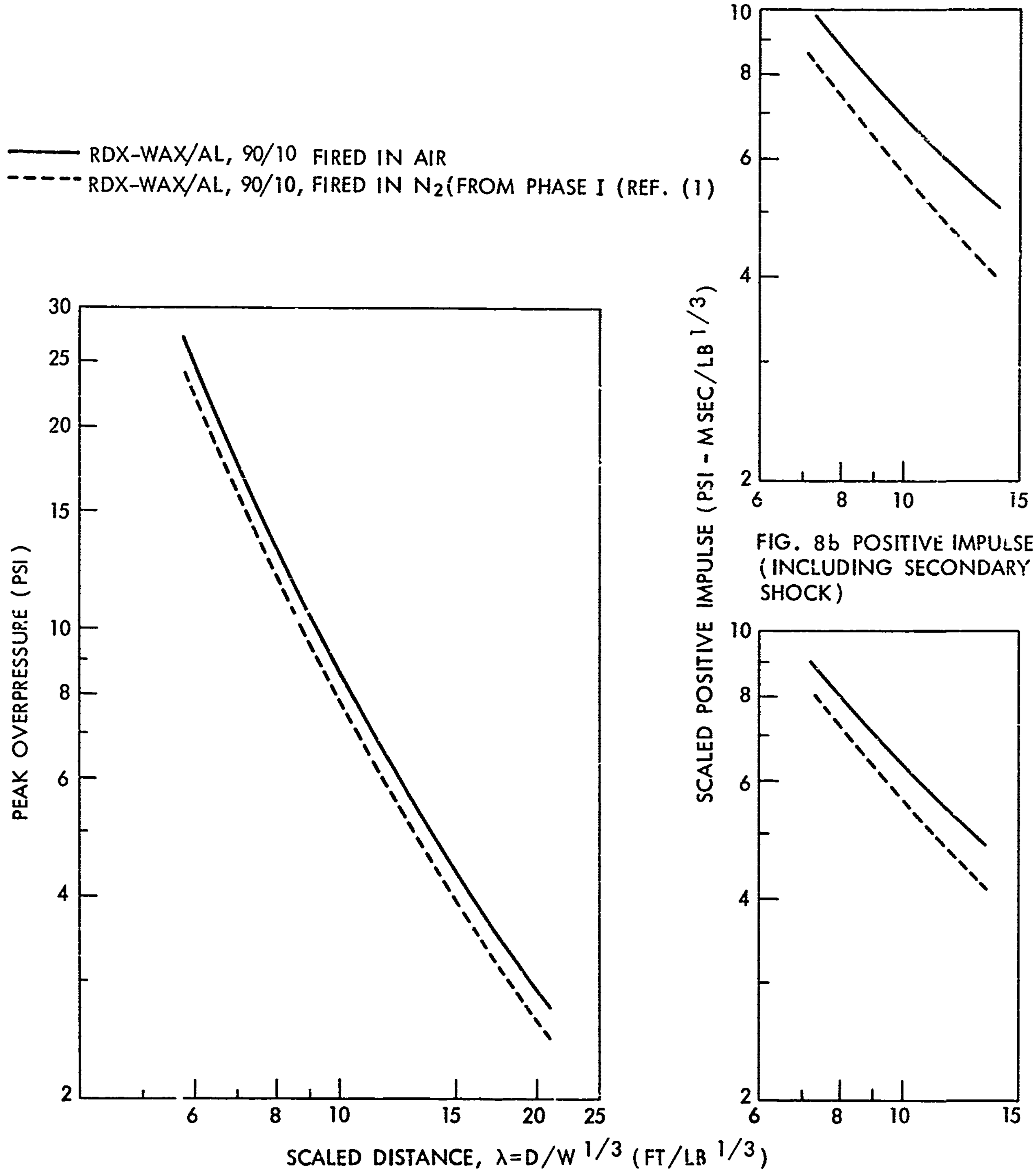


FIG. 8a PEAK OVERPRESSURE

FIG. 8b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 8c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 8 COMPARISON OF RDX-WAX/AL, 90/10, FIRED IN AIR AND N_2

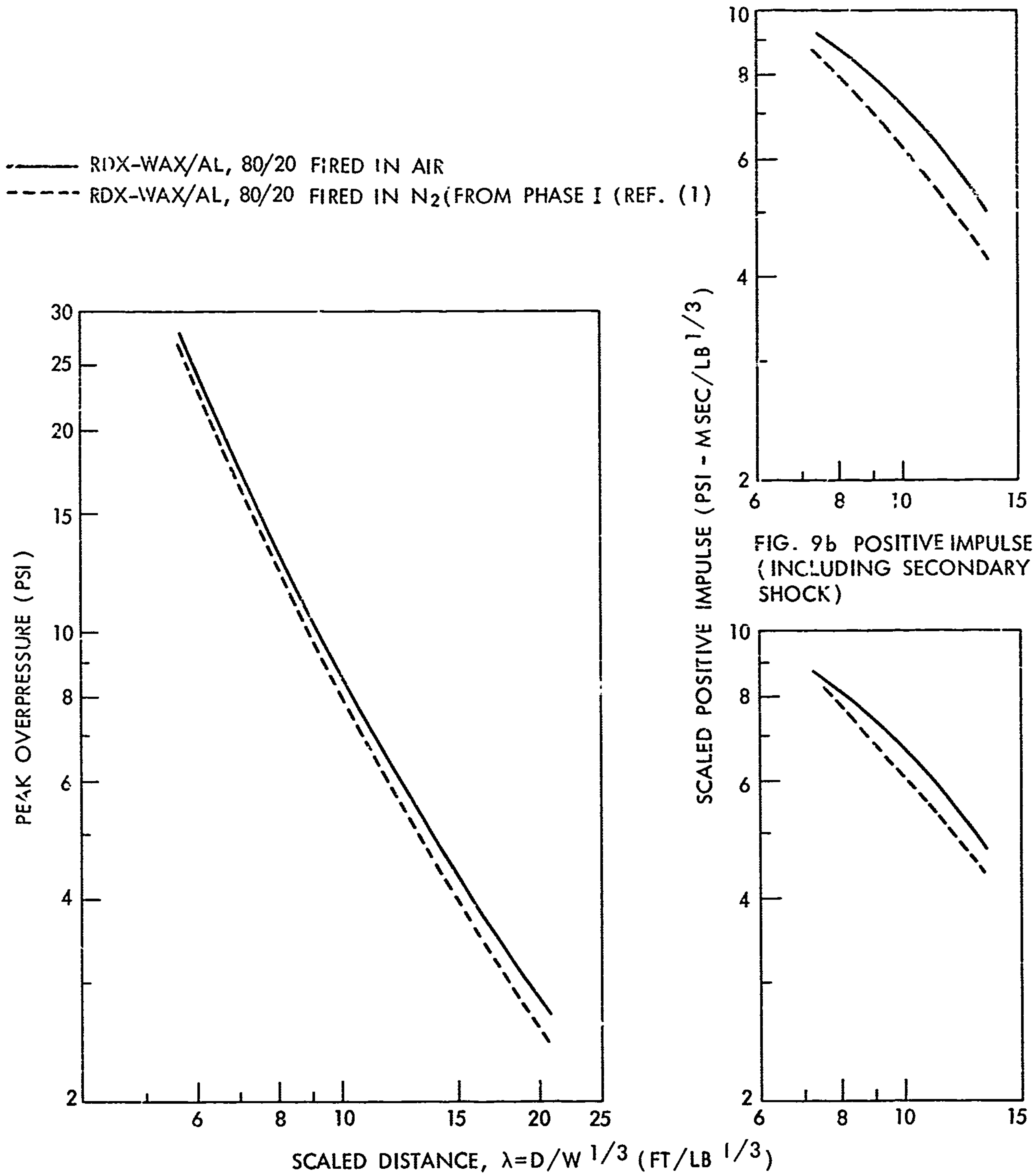


FIG. 9a PEAK OVERPRESSURE

FIG. 9b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 9c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 9 COMPARISON OF RDX-WAX/AL, 80/20, FIRED IN AIR AND N_2

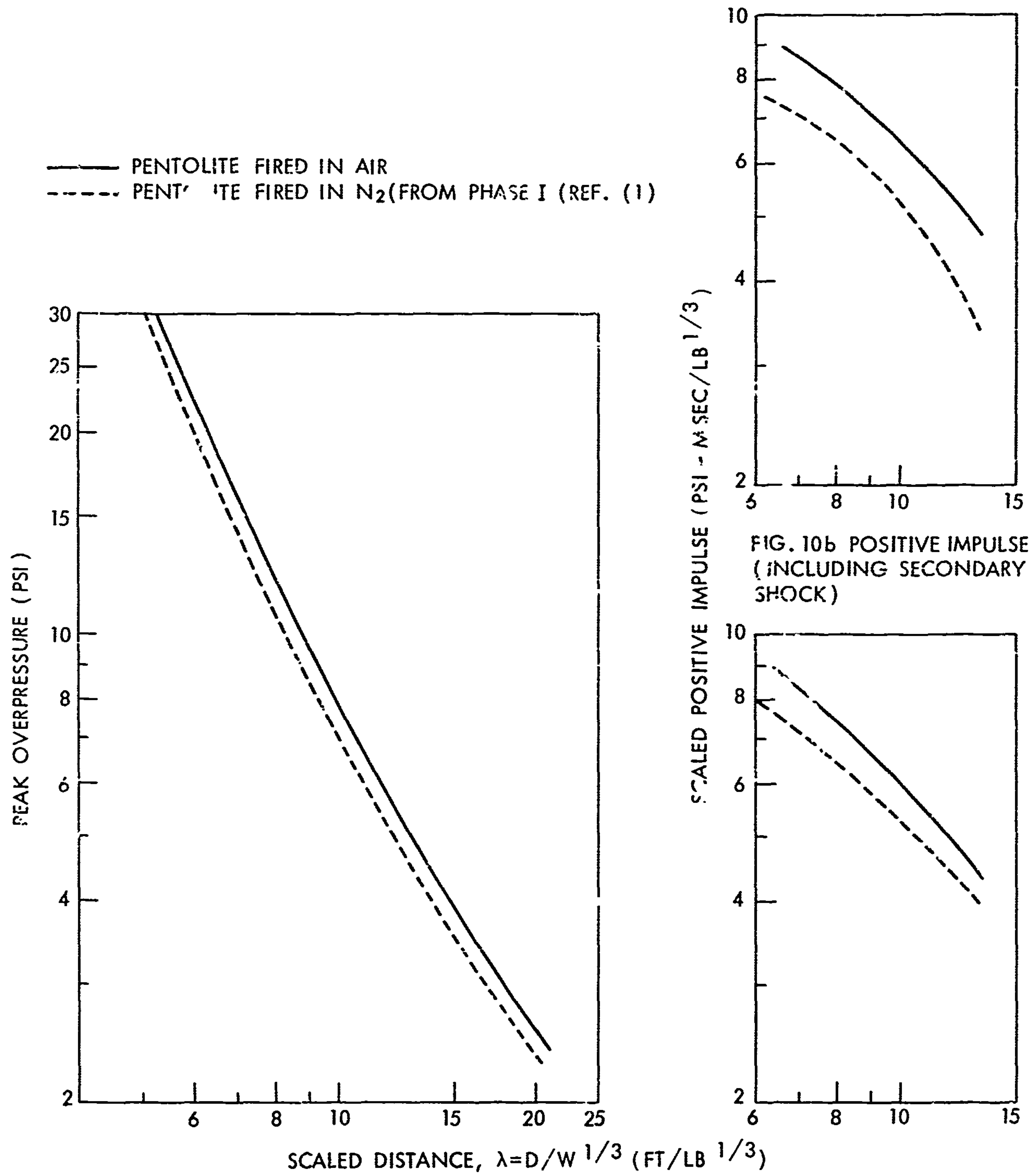


FIG. 10a PEAK OVERPRESSURE

FIG. 10b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 10c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

FIG. 10 COMPARISON OF PENTOLITE FIRED IN AIR AND N_2

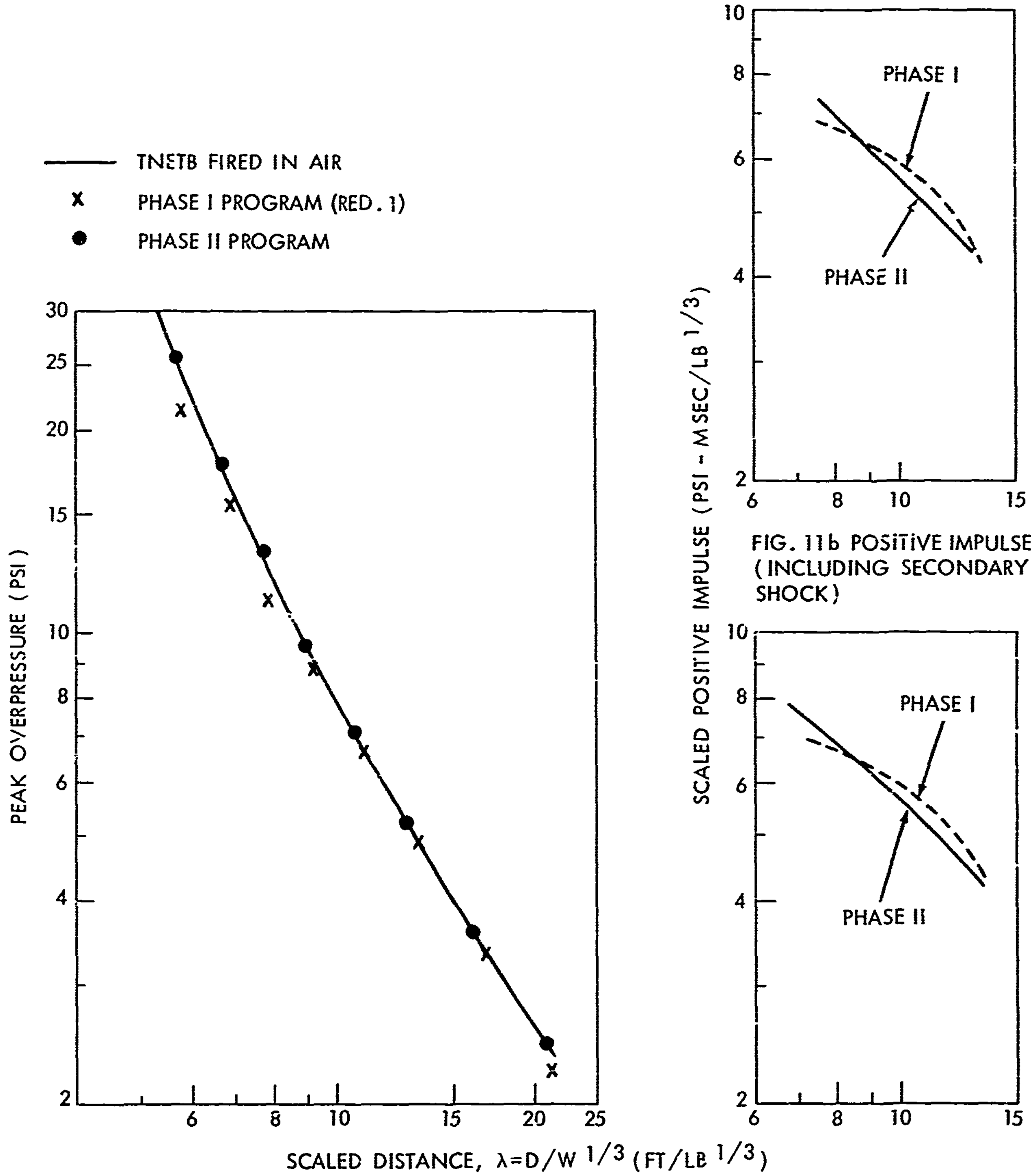
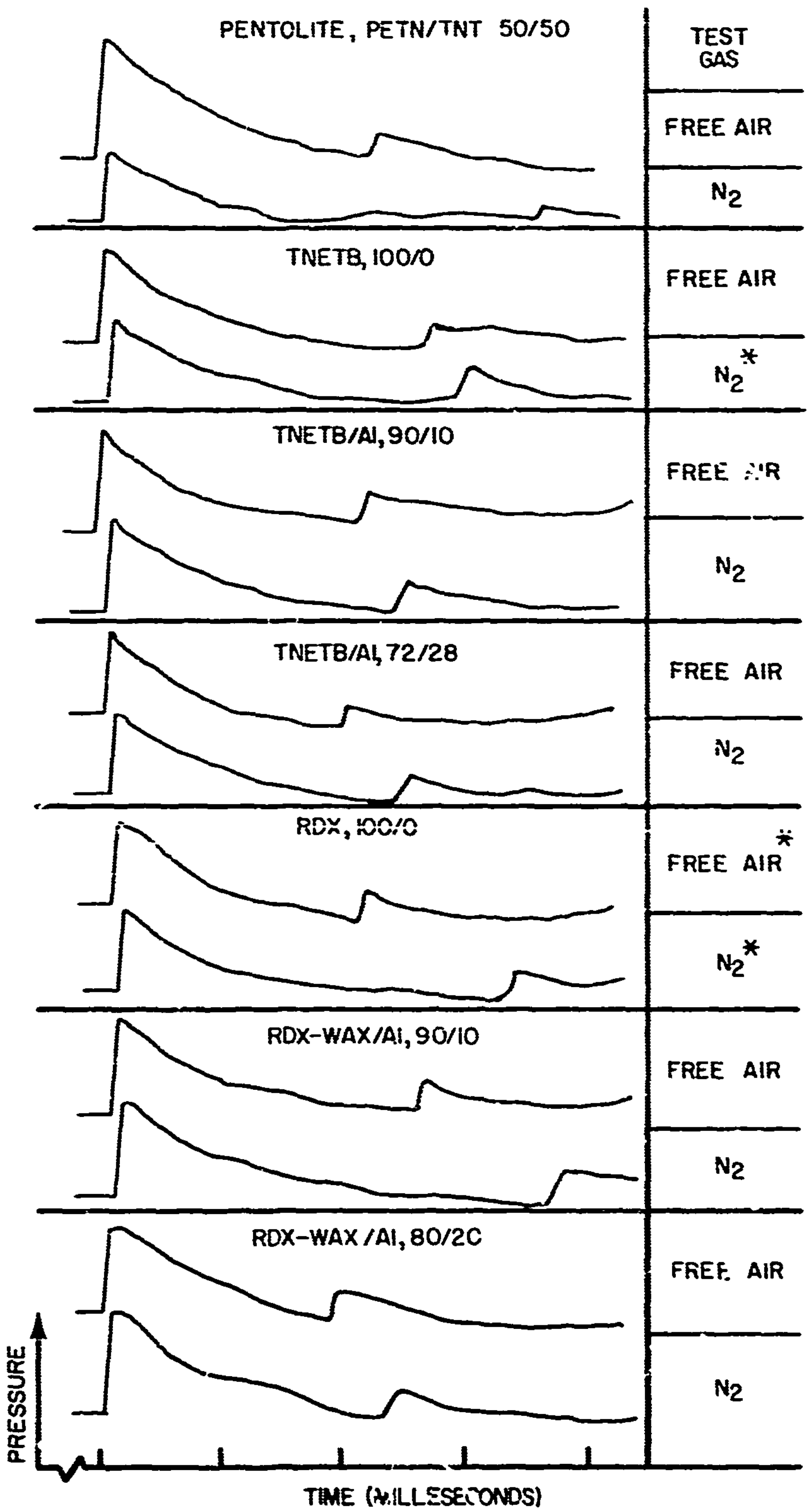


FIG. 11a PEAK OVERPRESSURE

FIG. 11b POSITIVE IMPULSE (INCLUDING SECONDARY SHOCK)

FIG. 11c POSITIVE IMPULSE (EXCLUDING SECONDARY SHOCK)

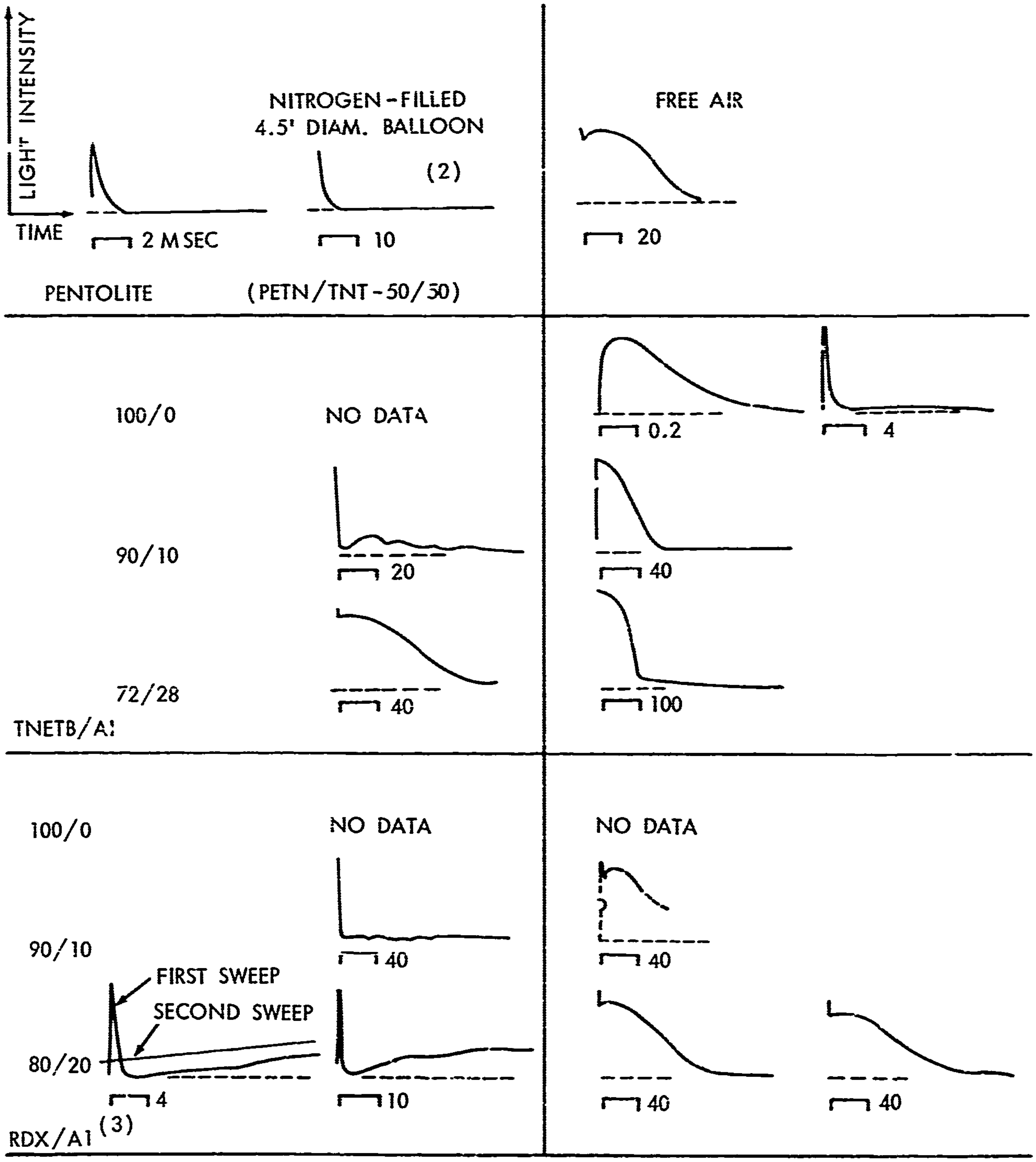
FIG. 11 COMPARISON OF DATA FROM PHASE I AND PHASE II CONTROL SHOTS (TNETB FIRED IN AIR)



NOTE:
CHARGE TO GAGE DISTANCE FOR ALL RECORDS = 7.70 FT.

* RECORDS FROM NAVORD REPORT 6234

FIG. 12 PRESSURE-TIME RECORDS SHOWING THE EFFECT OF AFTERBURNING ON POSITION OF SECONDARY SHOCK FROM 1-LB CHARGES (NOMINAL WT)



(1) ALL INTENSITIES REFERENCED TO SAME SCALE. NUMBERS ALONG ABSCISSAS INDICATE TIME IN MSEC. PER INDICATED DIVISION. DOTTED LINES INDICATE ZERO INTENSITY LEVELS.

(2) WHERE TWO RECORDS ARE SHOWN, A SECOND CHARGE OF THE SAME COMPOSITION WAS FIRED AND MEASURED.

(3) RDX CONTAINS 2% WAX.

FIG. 13 LIGHT INTENSITY VS TIME [1]